Some Acoustic Results from the Pratt and Whitney Advanced Ducted Propulsor - Fan 1

James H. Dittmar and David M. Elliott
Glenn Research Center, Cleveland, Ohio

Lawrence A. Bock
Pratt and Whitney, East Hartford, Connecticut

National Aeronautics and
Space Administration

Glenn Research Center

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SOME ACOUSTIC RESULTS FROM THE PRATT & WHITNEY ADVANCED

DUCTED PROPULSOR - FAN 1

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ABSTRACT

Noise measurements were obtained for the Advanced Ducted Propulsor (ADP) - Fan 1, with and without nacelle acoustic treatment. The fan was tested with no acoustic treatment (hard wall) and with acoustic treatment installed in three configurations in the nacelle (mid, mid plus aft, and fully treated). The hard wall results showed that the radiated noise from the fan came primarily from the aft end of the nacelle. At takeoff and higher speeds , the noise measured at the inlet angles was also found to be dominated by noise from the aft end. Significant amounts of attenuation were observed with acoustic treatment installed and comparison with predictions showed the treatment gave more attenuation than predicted. Effective Perceived Noise Levels were determined for a large hypothetical 4 engine airplane. These levels showed that the installed acoustic treatment provided as much as 5 EPNdB of noise reduction. A traverse with a probe having three microphones, one above the other, showed azimuthal variations in the noise that need to be further investigated.

INTRODUCTION

The NASA Advanced Subsonic Technology program has an ongoing noise reduction element to provide the technology to meet increasingly restrictive airport noise regulations and anticipated stricter noise standards. The goal of the program is to develop the technology to reduce the noise level of aircraft by a cumulative 30 dB relative to the noise levels represented by 1992 technology. This would be a noise reduction of 10 dB at each of the measuring stations - takeoff, sideline and approach.

As part of this effort, some initial tests were previously performed at both low speed (ref 1) and at cruise conditions (ref 2) for an existing 43.2 cm (17 inch) diameter Advanced Ducted Propulsor (ADP) model.. An improved ADP version with lower tip speed for more noise reduction was then designed by the Pratt & Whitney Division of United Technologies. This 55.9 cm (22inch) diameter fan, designated ADP Fan 1, was tested in the NASA Lewis 9 x 15 Foot Low Speed Wind Tunnel to investigate its noise characteristics. A photograph of this fan/nacelle located in the tunnel test section is shown in figure 1. The noise levels for this fan (ADP Fan 1), with and without nacelle acoustic treatment, are presented in this report.

APPARATUS AND PROCEDURE

ADVANCED DUCTED PROPULSOR

The Advanced Ducted Propulsor model, ADP Fan 1, has 18 rotor blades and is 55.9 cm (22 inch) in diameter (Fig.1) The primary noise reduction features of this fan are: low tip speed, variable blade stagger angle for cruise, takeoff and landing, cutoff vane numbers and large rotor-fan exit guide vane spacing. A cross section of the fan model is shown in figure 2. The fan model has 45 fan exit guide vanes (fegv) which cutoff the rotor-fegv interaction blade passing tone at takeoff speed. The model has a simulated flow through core which has 63 inlet vanes providing cutoff for the tones at blade passing frequency and twice blade passing frequency. Just downstream of the 63 core vanes are 16 support struts. The interaction of these struts with the rotor wakes may cause some blade passing tone noise.

The fan stage design is found in reference 3 and a table of design values is found in table 1. The ADP model fan was tested at its design takeoff blade stagger angle at speeds from 50 to 110 percent of its design takeoff speed.

ACOUSTIC MEASUREMENTS

Noise measurements were primarily obtained using one traversing microphone and two fixed microphones. All of the microphones were 0.635 cm (¼ inch) in diameter. Figure 3 is a top view of the tunnel test section showing the microphone arrangement. The traversing microphone moves along a 2.24 meter (88 inch) sideline in the same vertical plane as the model centerline with a measured angle range from 27 to 135 degrees. The data were all obtained with a tunnel axial Mach number of 0.1, resulting in emission angles ranging from 24.6 to 130.5 degrees. Two fixed microphones at 143.5 and 155 degrees (140 and 152.6 degrees emitted) were also used to

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obtain more aft angle data. The traverse data were obtained by moving the microphone, stopping and taking data, and then moving to the next stop. There were 48, equal measured angle, stops on the traverse. At each of the stops a 0 -8K Hz narrow band spectrum with 5.9 Hz bandwidth, and a 0 -80K Hz narrowband spectrum with 59 Hz bandwidth, were taken. These two spectra were then used to calculate a 1/3 octave band spectrum. Data were obtained from the two fixed microphones in the same manner. The data were corrected for microphone response, bullet nose receptivity, spherical spreading and atmospheric attenuation. All of the data in this report are presented as .3048 meter (1 foot) lossless data at the emitted angles unless otherwise noted.

During one test sequence, the single microphone stand on the traversing mechanism was replaced with a three microphone arrangement as shown in figure 4. This experiment was to determine if the noise pattern of the fan varied in the azimuthal direction.

ACOUSTIC TREATMENT

Acoustic treatment was applied in three locations as shown in figure 5; in front of the rotor (designated as "inlet" treatment), between the rotor and fan exit guide vanes (designated as "mid" treatment) and downstream of the fan exit guide vanes (designated as "aft" treatment). The inlet and mid treatments were only on the outer flow path surface while the aft treatments were on both the inner and outer flow path surfaces. A photograph of the inlet treatment is shown in figure 6. Figure 7 is a photograph taken from aft of the fan looking forward. The mid treatment can be seen on the outer surface in front of the fan exit guide vanes and the aft treatment can be seen on both the inner and outer surfaces behind the fan exit guide vanes. The sequence of testing started with the hard wall configuration then the mid liner was installed while the rest of the duct remained hard. The aft treatment , both inner and outer ,was then installed. The final configuration added the inlet treatment to make a completely treated configuration as shown in figure 5.

The design process for the acoustic treatment for the low speed fan used current Pratt and Whitney technology data bases and empirical and semi-empirical prediction tools. A comprehensive design process was started in 1990 to design the acoustic treatment for the Pratt & Whitney low speed fan, very high bypass ratio Advanced Ducted Propulsor full scale demonstrator engine. This design process lead to the selection of a single layer, linear, wire mesh on perforated plate face sheet over honeycomb type of liner. Once the general liner construction and impedance were defined, an iterative process was used to optimize the depth of the liners. This approach did not target a particular fan tone or mode structure to attenuate. Rather, typical engine spectra were predicted for a number of different liner depths ranging from 2.5 to 12.5 cm (1 to 5 inches). The attenuated spectra were "flown" in a computer flight simulation prediction code at a nominal set of flight conditions. The process defined a liner depth that resulted in the lowest predicted noise levels on an Effective Perceived Noise Level (EPNL) basis. The inlet depth was chosen based on minimizing EPNL for a nominal approach condition and the mid and aft liner depth was chosen based on minimizing EPNL at the cutback and sideline take off conditions. The design philosophy for the scaled liners to go into the 55.9 cm (22 inch) low speed fan model was simply to scale, as much as physically possible, the liners selected for the full scale demonstrator engine.

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The resulting design for all the model acoustic treatments consisted of a bonded, sandwich type construction, consisting of face sheet, honeycomb and an impervious backing sheet. The honeycomb cells were non-communicating. The face sheet was linear, consisting of randomly sintered fiber metal wires compressed into a sheet. Liner design details are shown in Table II. The liners, as constructed, were close to the design values but some differences did exist. For example, the inlet liner, exposed to the sound field of an impedance measurement device had an acoustic resistance of about 70 Rayls cgs and a non-linearity factor of less than 1.4. It was desired to have these properties as uniform as possible over the entire treated area, but individual values from 50 to 90 Rayls were measured. This variation was attributed to the random density of the sintered fiber metal face sheet and uneven flow of bonding agent at the honeycomb and face sheet interface. It was also desired to have a "one-piece" or seamless face sheet liner assembly. The flow contours of the inlet prevented a seamless design and the resultant assembly had one circumferential seam and four streamwise seams. The seams were approximately 0.5 cm 0.20 inch) in width. These differences in the liner resistance and the fact that it is not possible to exactly scale the liner may contributed to differences between the predicted and measured attenuations.

FAN OPERATING CONDITIONS

The primary data used in this report were taken at the takeoff, cutback and approach fan tip speeds of 256, 220 and 159 m/sec (840, 723 and 521 feet per second)., which correspond to corrected speed of 8750, 7525 and 5425 rpm respectively. Data at these speeds were obtained for all of the hard wall and acoustically treated configurations and for the hard wall data taken with the three microphone probe. The fan was operated with its blade stagger angle fixed at the takeoff setting for all of this testing. Therefore at the same rpm the fan was operating the same for each of the configurations and the data can be compared directly without the need to correct for differences in fan performance. The measured aerodynamic conditions for this fan are found in reference 4. Additional corrected speed points were taken for some of the test configurations and some of the data from these other conditions are also reported. These corrected speeds were 4200, 4848, 5900, 6700, 7032, 8073, 9115, 9636 and 9897 rpm which gave a tip speed range from 122 to 290 m/sec (400 to 950 feet/sec).

RESULTS AND DISCUSSION

HARD WALL

SPECTRA

The data taken with the surfaces of the fan duct in a hard wall configuration are presented in this section. Data are shown for the three spectra (0-8K Hz, 0-80K Hz, and 1/3 octave) at takeoff, cutback and approach speeds. Figure 8 shows the data at takeoff speed for a typical forward emitted angle of 49.8 degrees and figure 9 shows the takeoff speed at a typical aft emitted angle of 130.47 degrees. For ease of nomenclature, these angles will be referred to as simply 50 degrees and 130 degrees. In looking at the 0-8K Hz data, figures 8a and 9a, the tone at twice blade passing frequency, approximately 5300Hz, is clearly seen above the broadband level. The tone at blade passing frequency, approximately 2650 Hz, is cutoff and is not apparent

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in the spectra. When looking at the relative noise levels it can be seen that the levels at 130 degrees are significantly higher than those at 50 degrees for both the tone and the broadband noise. This aft noise domination will be discussed in detail later in the report.

The 0-80K Hz spectra at takeoff are shown in figures 8b and 9b. At 50 degrees, figure 8b, the tones at three, four and five times blade passing frequency are visible in addition to the twice blade passing tone . The tone at three times blade passing frequency is slightly higher than the one at twice blade passing frequency here in the inlet. At 130 degrees, figure 9b, the tones at 2, 3, 4, 5, 6, 8, and 9 times blade passing frequency are visible in the spectra. Here the tone at twice blade passing frequency is clearly the strongest at the aft angles. Again it can be seen that the fan is significantly noisier in the aft .

The change in the downward slope of the broadband noise around 50,000 Hz indicates a possible problem with the corrections applied to the data at these high frequencies. Therefore data at frequencies above 50,000 Hz are suspect and should not be considered as accurate. Differences between two data sets may be correct but the absolute levels are suspect. The data up to 50,000 Hz for this approximately 1/5th scale model is correct and would scale to 10,000 Hz and would be useable for full scale noise estimations.

The 1/3 octave data at takeoff are shown in figures 8c and 9c. In the front at 50 degrees, the 1/3 octave plot is fairly flat with small peaks at twice blade passing frequency and three times blade passing frequency, while in the back at 130 degrees a significant peak is shown at twice blade passing frequency. Again , as mentioned before, the noise is greater in the aft than in the front.

The data for lower fan speeds, cutback and approach, are presented in figures 10 through 13. Figures 10 and 11 are for the 50 and 130 degree angles at cutback and figures 12 and 13 are for the 50 and 130 degree angles at approach. These data show many similar trends as the takeoff data. In particular, they all show the aft noise domination of this fan. However, some differences from the takeoff speed data are apparent. First the blade passing tone is visible in some of the spectra. For example see figure 11a. Here, even though the rotor-fegv and rotor-core inlet interaction tones are cutoff, the blade passing tone is clearly visible around 2300 Hz. A possible source of this tone is the interaction of the rotor blade wakes with the 16 core duct support struts. It should be noted that this blade passing tone is at or below the broadband levels for the 1/3 octave data which indicates that it is not significant in the calculation of perceived noise.

The presence of the blade passing tone is also visible at lower speeds . For example the tone is seen at approach speed around 1650 Hz at both the forward angle , 50 degrees (figure 12a) and the aft angle, 130 degrees (figure 13 a), At this same speed side tones, which are not multiplies of the blade passing frequency, are present. These tones, multiplies of the shaft passing frequency, can be seen between the third and fourth blade passing frequency tones in figure 12a and around the second and fourth blade passing frequency tones in figure 13a. The exact reason for these extra tones has not been determined. They could possibly be the result of blade to blade surface differences or the result of differences in the blade spacing. This fan has a pin-root design such that the blades can rotate about this pin a slight amount in the circumferential direction when the fan is not spinning. As the fan is rotated, the blades are moved outward and " lock " into position. However, some differences in the spacing from blade to blade could exist resulting in these tones. Regardless of the reason, these side tones do exist at approach and lower speeds and may result in a small contribution to the overall noise of this

fan. At full scale, because of the frequency shift, these tones would not be in a highly weighted frequency range and would not be a major contribution to perceived noise levels.

DIRECTIVITIES

The directivities of the tone at twice blade passing frequency are shown in figure 14. These tone directivities were taken from the 0-8K Hz narrowbands where the tones are significantly above the broadband level. Figure 14a is for the takeoff condition, 14b for the cutback condition and 14c for approach. As can be seen the tone at twice blade passing frequency is higher in the aft than in the front at all of the fan speeds.

Figure 15 shows the directivities for a typical broadband region of the spectra around 6000 Hz. Part A is for the takeoff speed and part B is for cutback. The broadband is not shown for approach conditions because of the presence of side tones as discussed previously. In this figure it can also be seen that the aft broadband noise is greater than the front further indicating that this is an aft noise dominated fan in the hard wall configuration.

ACOUSTIC TREATMENT

AFT NOISE DOMINATION

Comparisons of directivities at twice blade passing frequency for the hard wall and acoustically treated cases are shown in figure 16 for the takeoff speed. Figure 16a shows the comparison when only the mid section acoustic treatment was present and shows little attenuation. When the aft treatment is added, figure 16b, significant attenuation is observed. Of particular interest are the large attenuations at the forward angles. This indicates that the noise radiated from the fan exhaust is dominating not only the aft quadrant but it is also the major contributor in the front. Figure 16c shows the full treatment installation where the inlet treatment is added to the mid and aft treatments of figure 16b. The attenuations in the back are the same with some additional attenuations in the front as would be expected from the added inlet liner. These additional inlet attenuations would not have been seen with the inlet liner alone because the untreated aft noise controlled these forward angles. Figure 17 is the mid plus aft liner configuration compared with the hardwall for the tone at three times blade passing frequency. Again, it can be seen at the takeoff condition, that the aft radiated noise is controlling the noise at the forward angles. Forward angle broadband noise is also being controlled by the aft radiated noise. Figure 18 is an example for the takeoff speed broadband noise at 6000 Hz with the mid plus aft treatment directivity compared with the hard wall directivity. The frequency range over which the aft noise dominates the noise at the forward angles is fairly large. Figure 19 shows 1/3 octave data at the 50 degree angle at takeoff speed. As can be seen, the noise at this forward angle is attenuated at frequencies from approximately 2,000 to 20,000 Hz when the mid plus aft treatment is installed.

This aft noise domination of the forward angle noise occurs at the takeoff and higher speeds. The twice blade passing frequency directivities for hard wall and mid plus aft treatment are shown in figure 20 at 9636 rpm for example. At speeds below takeoff, the aft noise was louder than the forward noise but the aft noise did not control the noise at the forward angles. The directivities at cutback speed are shown in figure 21. The mid treatment directivity shows a slight noise decrease in the forward angle noise, figure 21a. This is likely the rotor-stator interaction noise, generated on the stator, that is removed by the mid liner as it radiates upstream

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in the duct. The addition of the aft treatment, figure 21b, shows significant noise reduction in the aft but little in the front. In comparing figure 21a and figure 21b, it appears that the inlet noise reduction observed with the mid plus aft treatment is probably that which was removed by the mid liner alone (Figure 21a). At this cutback speed and at lower speeds, the aft noise dominates in the rear but the inlet angles, 70 degrees and forward do not appear to be dominated by aft noise.

TREATMENT ATTENUATIONS

The measured treatment performance is found in figures 22 through 26. Figure 22 shows the hard wall and fully treated configuration 1/3 octave spectra at takeoff speed. Figure 22a shows the two curves at the 50 degree inlet angle. The peak attenuation is close to 10 decibels with attenuations seen over a broad frequency range. The 90 degree data are shown in figure 22b. Here the frequency range of the attenuations is broader than normally seen for this type of liner. Single degree of freedom liners typically have a relatively narrow frequency band where noise is attenuated. A typical liner of this type might have ½ of the peak attenuation at 1 ½ to 2 times the frequency where the peak attenuation was observed and show little or no attenuation at 3 to 4 times the peak attenuation frequency. For example see figure 16 of reference 5. With the peak attenuation around 4000 to 5,000 Hz for this liner, the attenuations at 20,000 Hz and above would be expected to be near zero. Therefore the attenuations in the region from 30,000Hz to 50,000 Hz are noteworthy. This same broad frequency range of attenuation is seen at the other aft angles. The data at 130 degrees are shown in figure 22c.

The actual attenuations are shown in the following figures. Figure 23a shows the attenuations (hard wall - fully treated) in the inlet at 50 degrees for the takeoff condition. The amount of attenuation is more than would be predicted from the amount of inlet lining material alone . This attenuation is most likely the result of the aft liner attenuation on the aft noise which dominates the noise at inlet angles for this condition. At the farther aft angles, the large frequency range of attenuation becomes evident. At 90 degrees, figure 23b, attenuations at frequencies from 2,000 to 50,000 Hz are seen. This large frequency range of attenuation is also seen at other aft angles. The attenuations for 130 degrees are seen in figure 23c. The frequency range is more than normally expected. The possibility of a change in microphone response was investigated. However, since the forward angles are taken with the same traversing microphone without the large range of attenuation and since the sound pressure levels with and without acoustic treatment correspond below 1,000 Hz this is not likely the cause of the large frequency range of attenuation. (The microphone was also removed and a check of its calibration showed that this was not the cause) The possibility of a bad data set for the full liner test was also considered, so the data with the mid plus aft treatment were also compared. Figure 24 shows the mid plus aft treatment attenuation at the 130 degree aft angle location. Here the mid plus aft treatment and the full treatment would be expected to give the same results. The mid plus aft liner gives almost the identical attenuations as did the full treatment (figure 23c). The very small differences between the two are likely an indication of the repeatability of the data in this facility. This good comparison indicates that the full treatment data does not have a measurement error.

Other speeds were also investigated. The large range of frequency attenuation in the aft is present at all speeds above takeoff. Figure 25 shows the high frequency attenuation is clearly present at 9636 rpm, 130 degrees. The large frequency range of attenuation is not present at

lower speeds. For example, figure 26a shows the 130 degree attenuation for the cutback speed and figure 26b shows the approach attenuation. As can be seen, the high frequency attenuation is not present.

A comparison was then made of the hard wall data at cutback speed and at takeoff speed. (The treatment showed high frequency attenuation at takeoff speed but not at cutback.) Figure 27a shows 1/3 octave spectra at the 50 degree inlet angle for both cutback and takeoff. As can be seen, the small increase in speed results in the expected small noise increase. In figure 27b at the 130 degree aft angle, a large noise increase is observed in going from cutback to takeoff speed. In particular this noise increase occurs at the high frequencies. It appears that at takeoff and higher speeds increased noise is produced in the aft at high frequencies.

It may be that when the hardware change is made from hard wall to the liner configuration the source is removed or it may be that the liner is particularly effective in removing this high frequency noise. If it is the acoustic treatment removing this extra noise then the scale liners are acting differently than would be expected based on typical full scale liner behavior. This may indicate a problem with scaling acoustic liners that needs to be investigated.

PREDICTED-MEASURED ACOUSTIC TREATMENT RESULTS

Acoustic treatment predictions were compared with the measured results. The attenuation predictions were based on combining separate inlet and aft predictions into a total attenuation matrix.. Figure 28 shows the measured data (solid line) compared with the predicted data (circles) at the takeoff condition. Figure 28a shows the inlet attenuation at the 50 degree position. As can be seen, the measured attenuation is significantly higher than predicted. As mentioned before, this is most likely the result of the aft noise domination of the inlet angles noise and the measured inlet angle attenuations are the aft liner attenuation aft noise which had radiated to the forward angles.

Figure 28b shows the comparisons at 130 degrees. Here the predicted level of the peak attenuation is approximately the same as the measured peak. The predicted peak however occurs lower in frequency than the measured peak. This may be the result of the model treatment impedence characteristics not being exactly the same as used in the predictions or it may indicate a problem in scaling with the prediction method itself. The measured attenuations at high frequency, 20,000 Hz and above, are significantly greater than predicted at this takeoff condition and, as mentioned before, may be an indication of problems in physically modeling full scale liners.

At cutback and lower speeds, the extra high frequency attenuation in the aft was not observed. Figure 29 shows the attenuation comparison at 130 degrees. Here the shape of the predicted and measured attenuations are similar. The prediction is still showing the attenuations at lower frequencies than the data. As discussed before, this may be a scaling problem in the prediction method for determining the frequency of the pek attenuation.

The predicted attenuations at inlet angles were done assuming only inlet liner attenuations. In order to separate out the effect of only the inlet treatment on the measured data, attenuations were calculated between the fully lined configuration and the mid plus aft configuration. Figure 30 shows this comparison. The predicted level and shape of the attenuation are similar to the

measured data but again the predicted attenuation is shifted lower in frequency than the measured attenuation.

EFFECTIVE PERCEIVED NOISE LEVEL ATTENUATIONS

The observed acoustic treatment attenuations would have a significant influence on the Effective Perceived Noise of an airplane. To evaluate the effect, the model data were scaled to a fictitious ADP product application. This application is for a very large four engine aircraft with 3.3 meter (130 inch) diameter , low fan pressure ratio, very high bypass ratio, engines of approximately 267,000 newtons (60,000 lbs) rated thrust each. The 59 Hz (0 to 80 k) narrowband data were synthesized into 1/3 octave band data using a Pratt & Whitney algorithm that simulates a filter shape equal to an IEC-225 filter specification and does band sharing on tones where appropriate. The analysis proceeded with inputing the one third octave band SPL data into Pratt & Whitney's computer simulation of a flyover event. The fan noise alone data was scaled to full size and was "flown" at three flight conditions representing approach, cutback, and takeoff over a range of fan speeds at each condition to produce the EPNL's. A simulated airframe noise contribution was added to the approach condition.

The results are shown in figures 31 through 33. Figure 31 is for a range of fan speeds around the approach flight condition with the airframe noise added, figure 32 is for cutback and figure 33 is for takeoff. The plots show results for the hard wall and three treated configurations. The small mid liner acting alone, in the absence of either a treated inlet or treated aft duct provided from 0.5 to 1.0 EPNdB fan noise suppression. At the very low fan speeds around the approach condition, airframe noise began to dominate the flyover noise. When the aft duct liner was added, the attenuations increased significantly at all three conditions to about 2 EPNdB at the higher approach and cutback speeds and up to 4 or 5 EPNdB at the takeoff range of speeds. The addition of the inlet liner showed a very small reduction in EPNdB at approach and takeoff speeds and about a 1 EPNdB reduction in the cutback speed range. The small benefit of the inlet treatment again points to the dominance of the noise signature by the aft radiated noise. These noise reductions of up to 5 EPNdB would provide a significant lowering of airplane noise.

THREE MICROPHONE TRAVERSE

As indicated previously, some traverse measurements were taken with a probe containing three microphones, one above the other, to investigate the variation of the noise in the azimuthal direction. The results for the tone directivities at twice blade passing frequency are shown in figures 34, 35 and 36 for takeoff, cutback, and approach conditions respectively. In each of these figures, part A compares the top and center microphones, part B compares the center and bottom microphones and part C compares the top and bottom microphones. As can be seen from these comparisons the general shapes of the tone directivities are similar. For example in figure 34 A, the peak noise is in the aft around 120 degrees and is 15 to 20 dB higher than the inlet noise for both the top and center microphones. However, significant differences exist in the angle to angle noise levels. Some specific angles show as much as 10 decibels difference from microphone to microphone. See for example figure 34 C at 80 degrees.

These large differences in the tones with circumferential angle are of significant concern. For example, traverses taken at different azimuthal angles for two different fans may give the wrong comparison between the noise of these two fans. Further work needs to be done to determine the magnitude of this azimuthal variation and measure any patterns of repetition in the circumferential direction. An experiment to do this would require more than the three azimuthal positions used here. If these azimuthal variations are confirmed then some azimuthal measurements may be necessary as part of a fans evaluation in the future.

CONCLUDING REMARKS

Noise measurements were obtained for the ADP Fan1 with and without nacelle acoustic treatment. The fan was tested in four configurations: 1. Hard wall 2. Acoustic treatment installed between the rotor and the fan exit guide vane, the mid liner configuration, 3. The mid liner plus acoustic treatment installed aft of the stator, mid plus aft configuration, and 4. Inlet treatment added to the mid plus aft configuration, fully treated configuration. The fan noise levels for these configurations are presented in this report. Fan noise directivities for the hard wall case indicate that this fan is aft noise dominant having significantly higher noise levels in the aft than in the front at all of the fan speeds tested. The mid treatment configuration provided a very small noise reduction. When the aft treatment was added, mid plus aft configuration, significant aft noise reductions were observed. At the takeoff and higher speeds, significant noise reductions were also observed in the inlet. This indicates that the aft noise was even dominating the inlet arc at these speeds. The addition of the inlet treatment, showed some small additional noise reductions.

The fully treated configuration showed significant amounts of attenuation when compared with the hard wall case. These reductions were over a large frequency range. In the aft at speeds above takeoff, the attenuations were over a frequency range from 2,000 to 50,000 Hz which is broader than the range normally seen for this type of liner.

Comparisons of the liner attenuations with predictions showed the liners gave more attenuation than predicted, particularly at frequencies above 20,000 Hz in the aft at takeoff and higher speeds. The peak magnitude of the predicted attenuations were similar in level to the measured levels but occurred at lower frequencies. The differencies in the measured and predicted attenuations may be a result of the acoustic treatment properties being different than the values used in the predictions, a problem with the prediction method itself or some other as yet unknown effect of scaling liners to this small size. Further study will be necessary to determine that measured attenuations on these scaled models could be used to predict full scale treatment performance.

Effective Perceived Noise Level attenuations were calculated for a hypothetical full size 4 engined airplane. The acoustic treatment showed approximately 4 ½ EPNdB reduction at cutback and 5 EPNdB reduction at takeoff.

Experiments were also performed using a traversing probe with three microphones, one above the other, to investigate the variation in noise with azimuthal angle. The general shapes of the tone directivities of the three microphones were similar all showing the aft noise domination of the fan. However, the presence of differences as large as 10 dB exist in the angle to angle noise levels are of significant concern and should stimulate more effort toward predicting and measuring these azimuthal variations.

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TABLE I   PRATT & WHITNEY ADP FAN 1

TAKEOFF TIP SPEED	840 FT/SEC
TAKEOFF PRESSURE RATIO	1.28
ROTOR BLADE NUMBER	18
BYPASS STATOR VANE NUMBER	45
CORE STATOR VANE NUMBER	63
ROTOR STATOR SPACING IN AXIAL FAN CHORDS AT MID SPAN	1.8

TABLE II MODEL ACOUSTIC TREATMENT DESIGN SUMMARY

	Resistance	NLF	Face Sheet thickness	Honeycomb cell size	Honeycomb Depth	App Area
Inlet	70	< 1.4	0.020 in 0.05 cm	0.19 in 0.47 cm	0.5 in 1.27 cm	3.5 ft² 0.33 m²
Fan Case OD	45	< 1.4	0.020 in 0.05 cm	0.19 in 0.47 cm	0.5 in 1.27 cm	1.8 ft² 0.17 m²
Fan Duct OD	45	< 1.4	0.020 in 0.05 cm	0.19 in 0.47 cm	0.5 in 1.27 cm	5.0 ft² 0.46 m²
Fan Duct ID	45	< 1.4	0.020 in 0.05 cm	0.19 in 0.47 cm	0.5 in 1.27 cm	4.0 ft² 0.37 m²

Figure 1.—Pratt and Whitney ADP Fan 1.
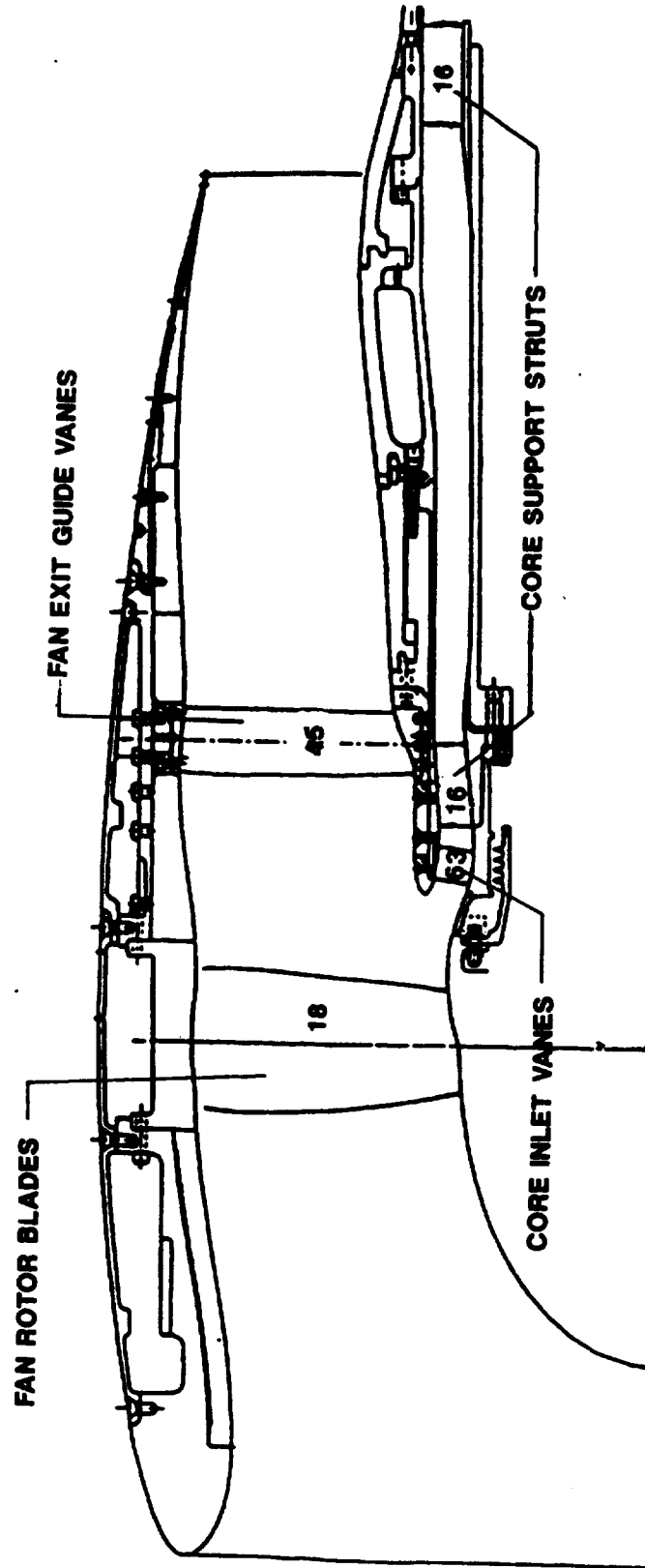
FIGURE 2 HARDWALL LINER CONFIGURATION

FAN EXIT GUIDE VANES

CORE SUPPORT STRUTS

FAN ROTOR BLADES

CORE INLET VANES

FIGURE 3 MODEL IN 9X15 TEST SECTION

MICROPHONE STOPS

FIXED MICROPHONES

178.74

88.00

65

40.8

59.37

TRAVERSING MICROPHONE

343.20

2

1

155 (152.6)

(130.5) 135

(140) 143.5

27 (24.6)

146.10

192.06

50

3
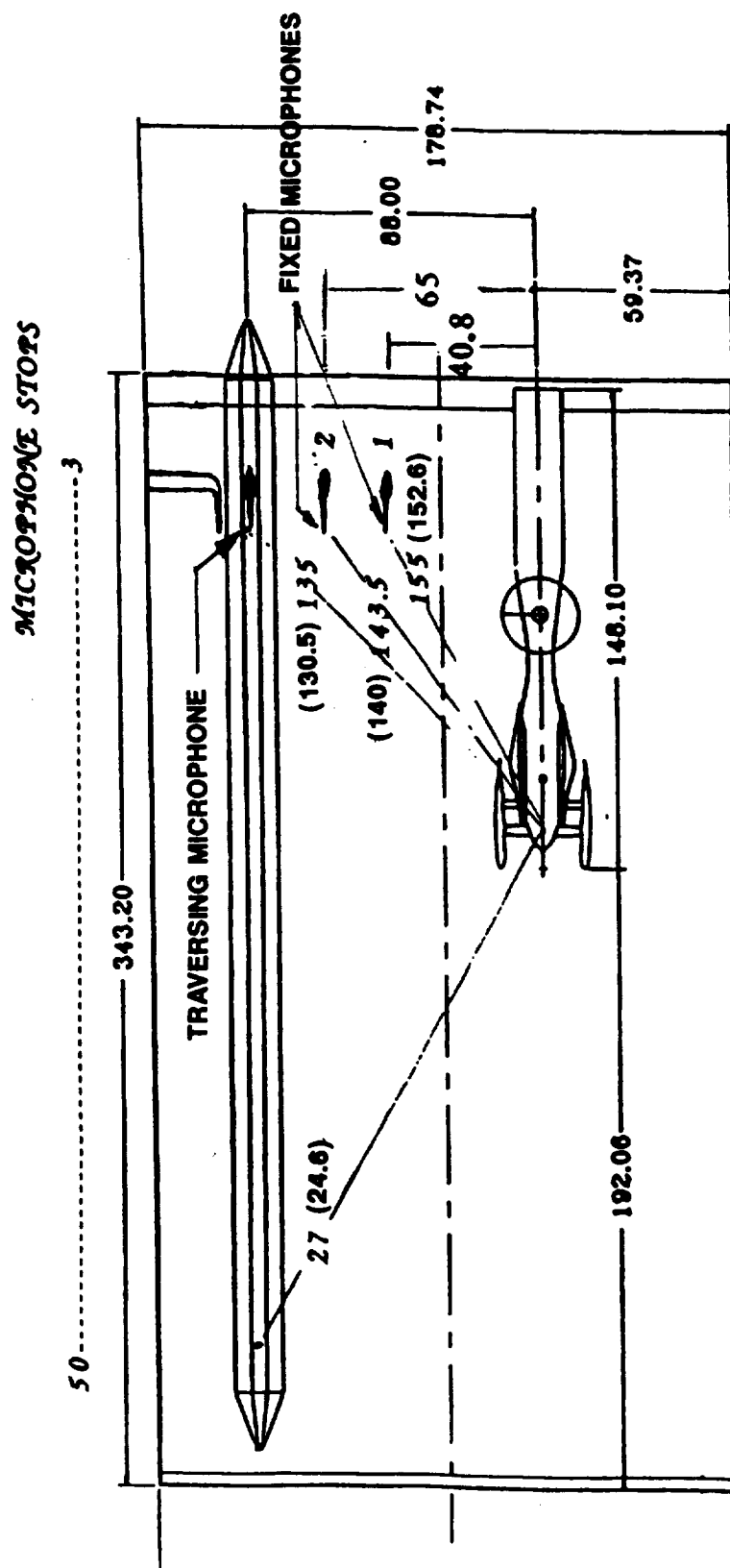
TOP VIEW

MEASURED ANGLES
(EMITTED ANGLES)
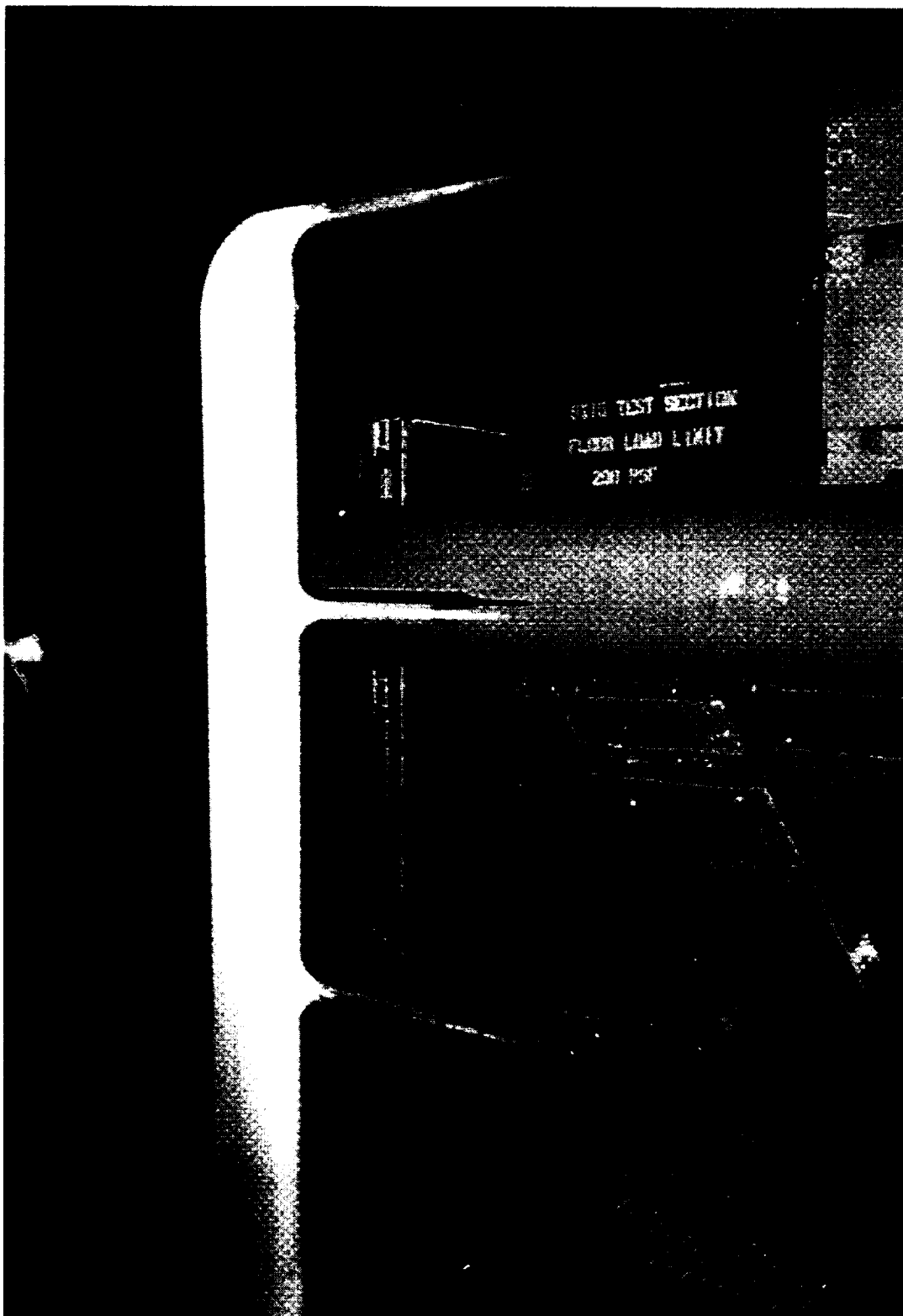
Figure 4.—Three microphone probe. (a) Photograph.
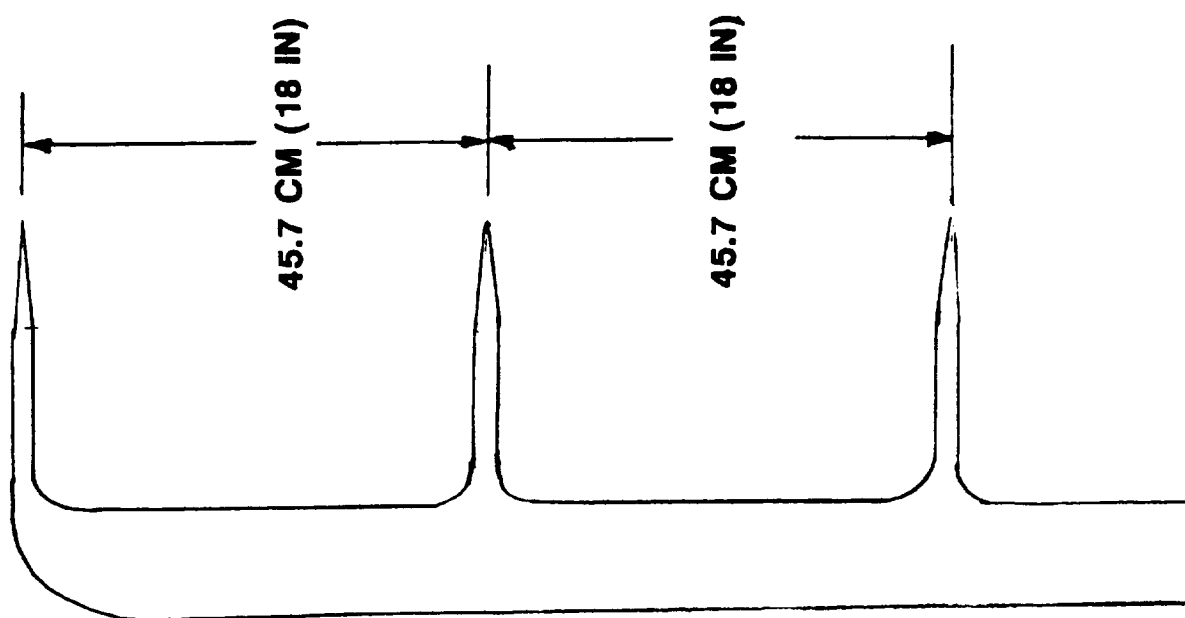
FIGURE 4 CONCLUDED. (B) SKETCH.

45.7 CM (18 IN)

45.7 CM (18 IN)

17

INLET

MID

AFT
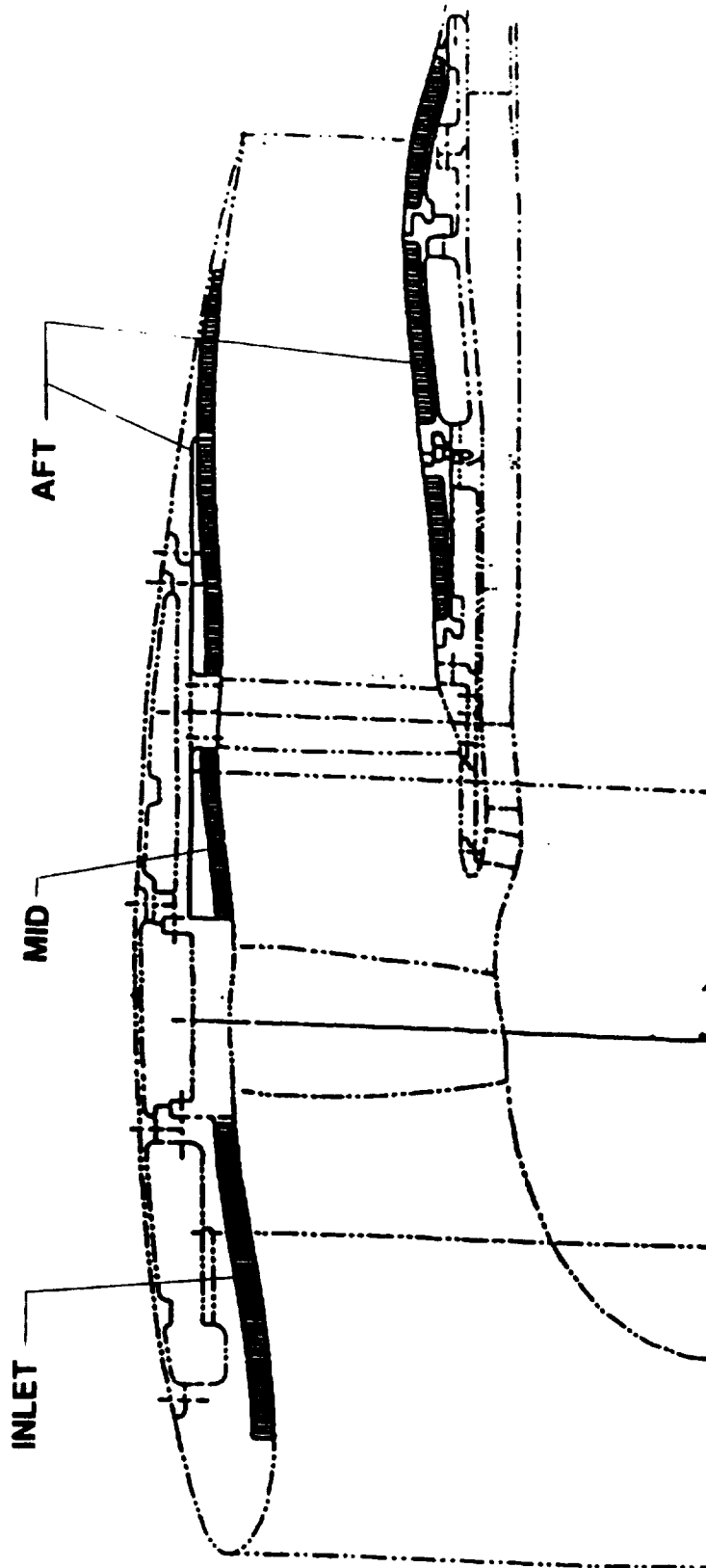
FIGURE 5   ACOUSTIC LINER LOCATIONS

18
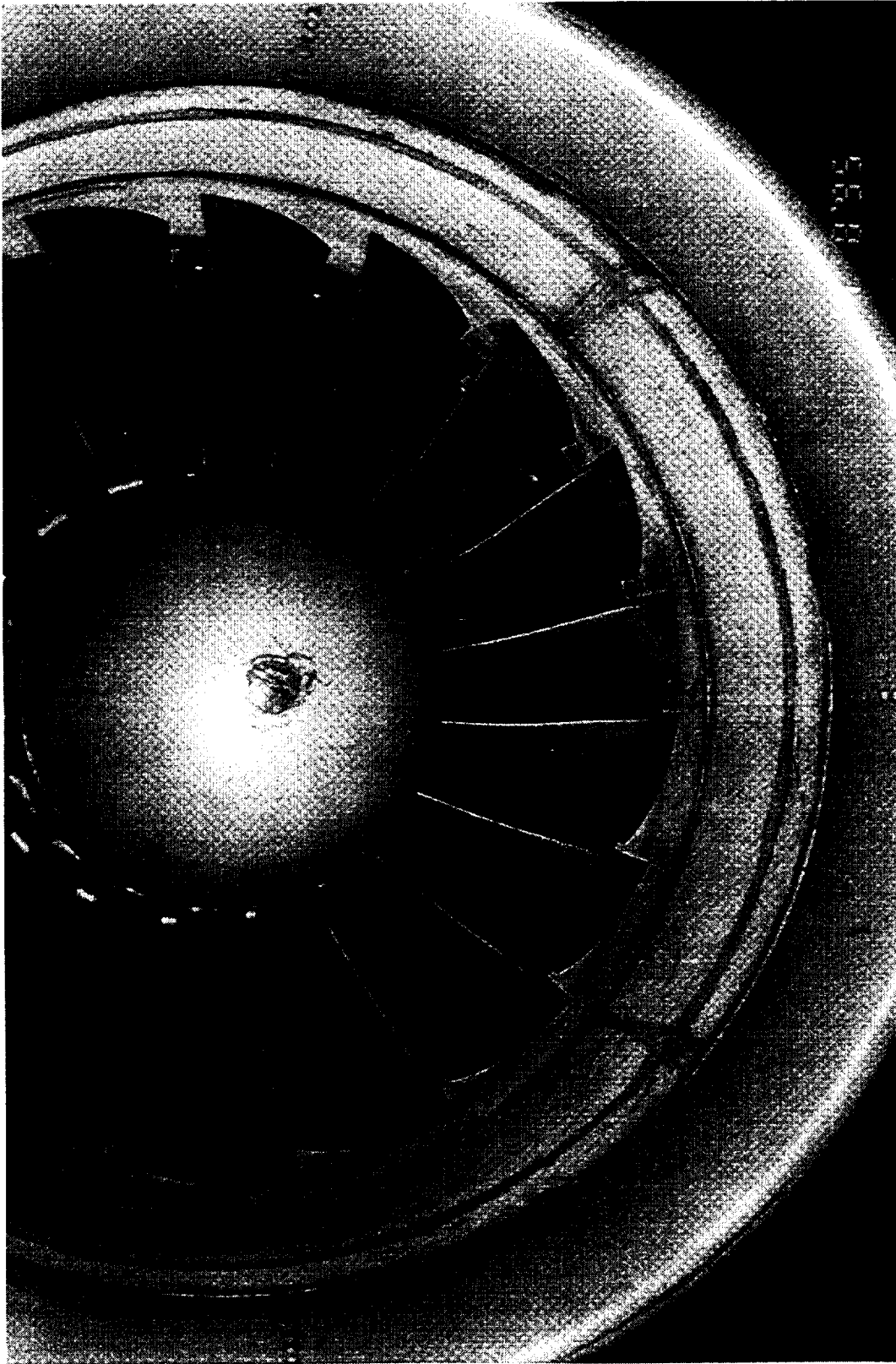
Figure 6.—Inlet liner.

19
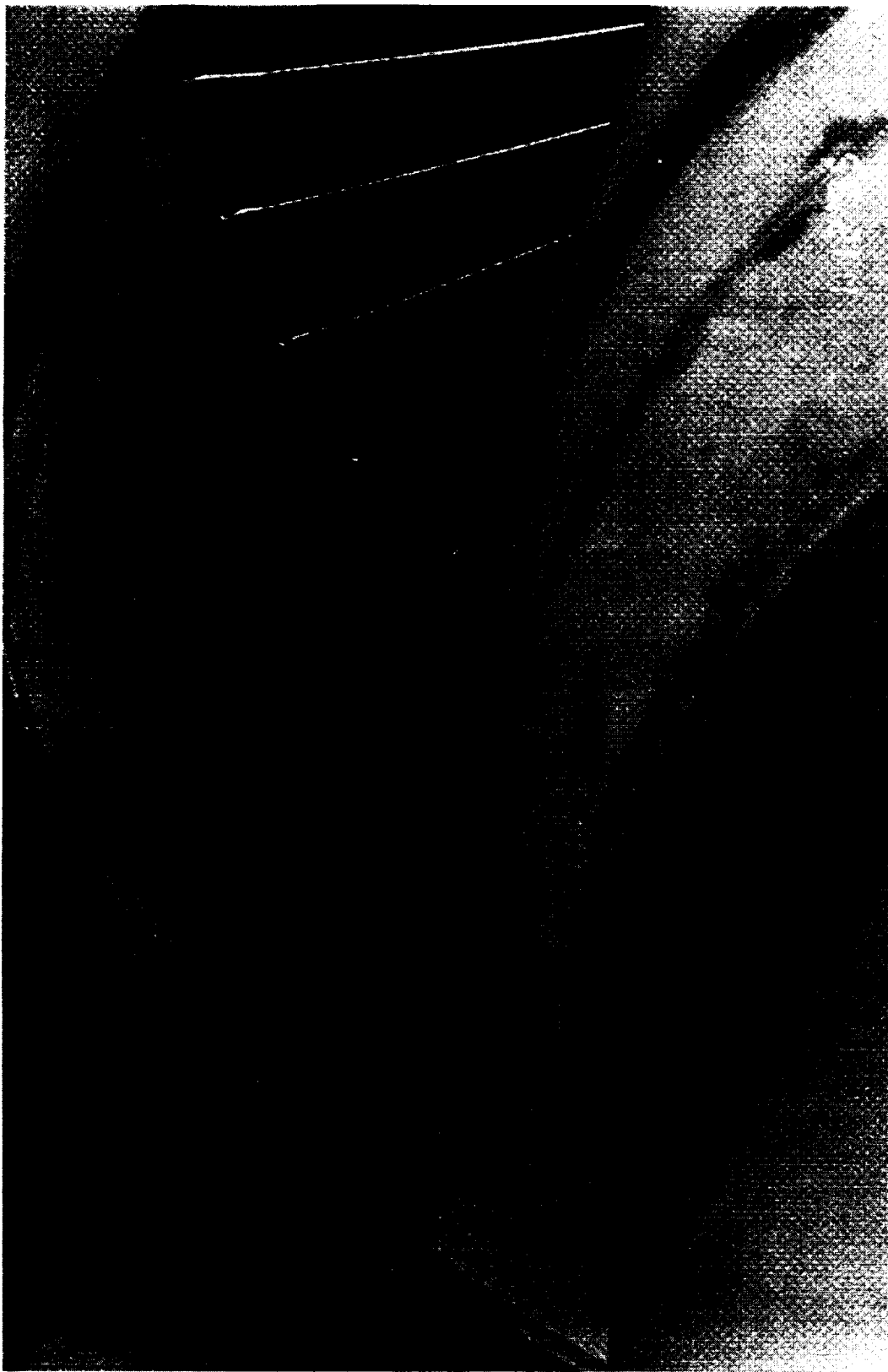
Figure 7.—Mid and aft liners.

20
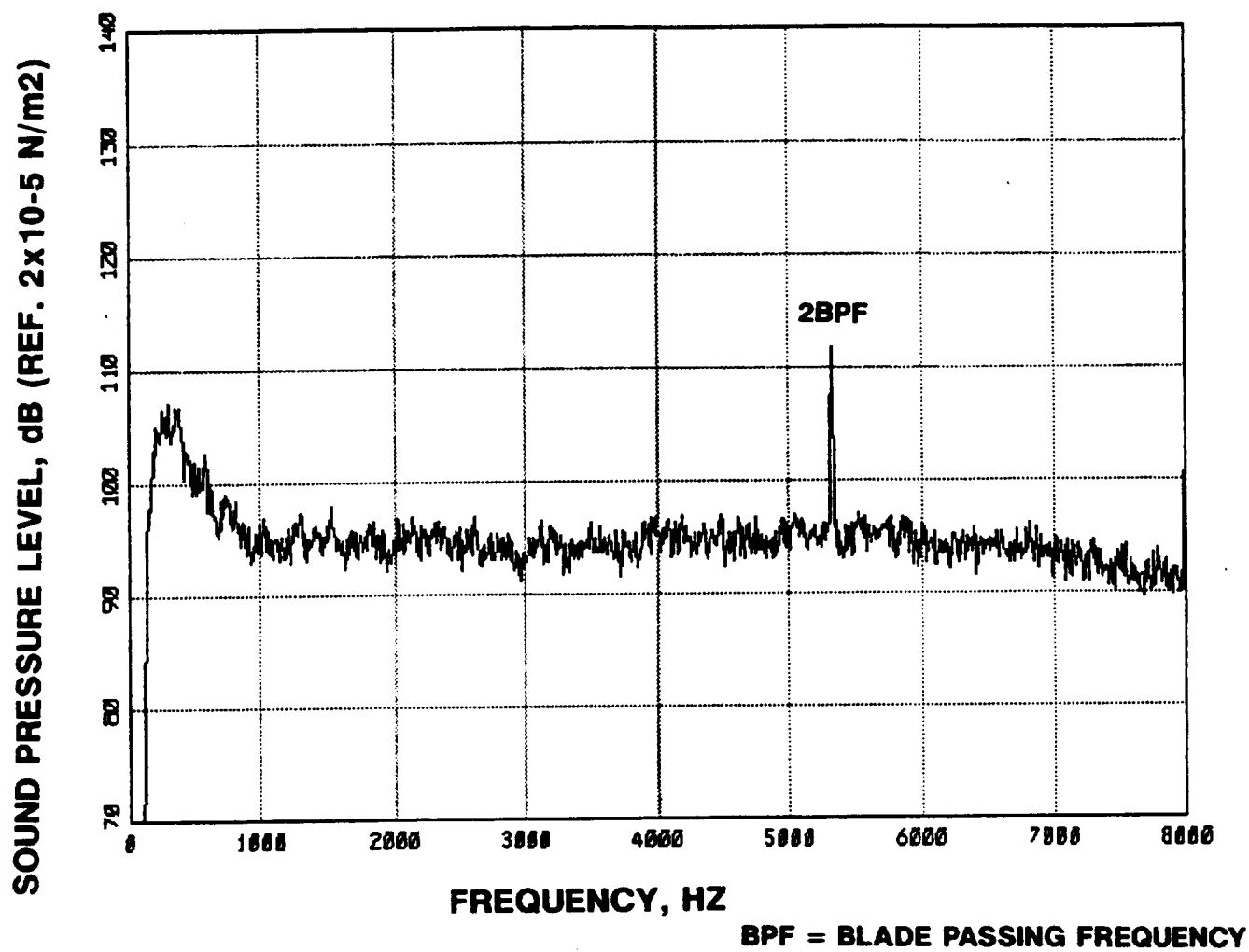
FIGURE 8 TAKEOFF SPEED, HARDWALL CONFIGURATION,

50 DEGREE ANGLE
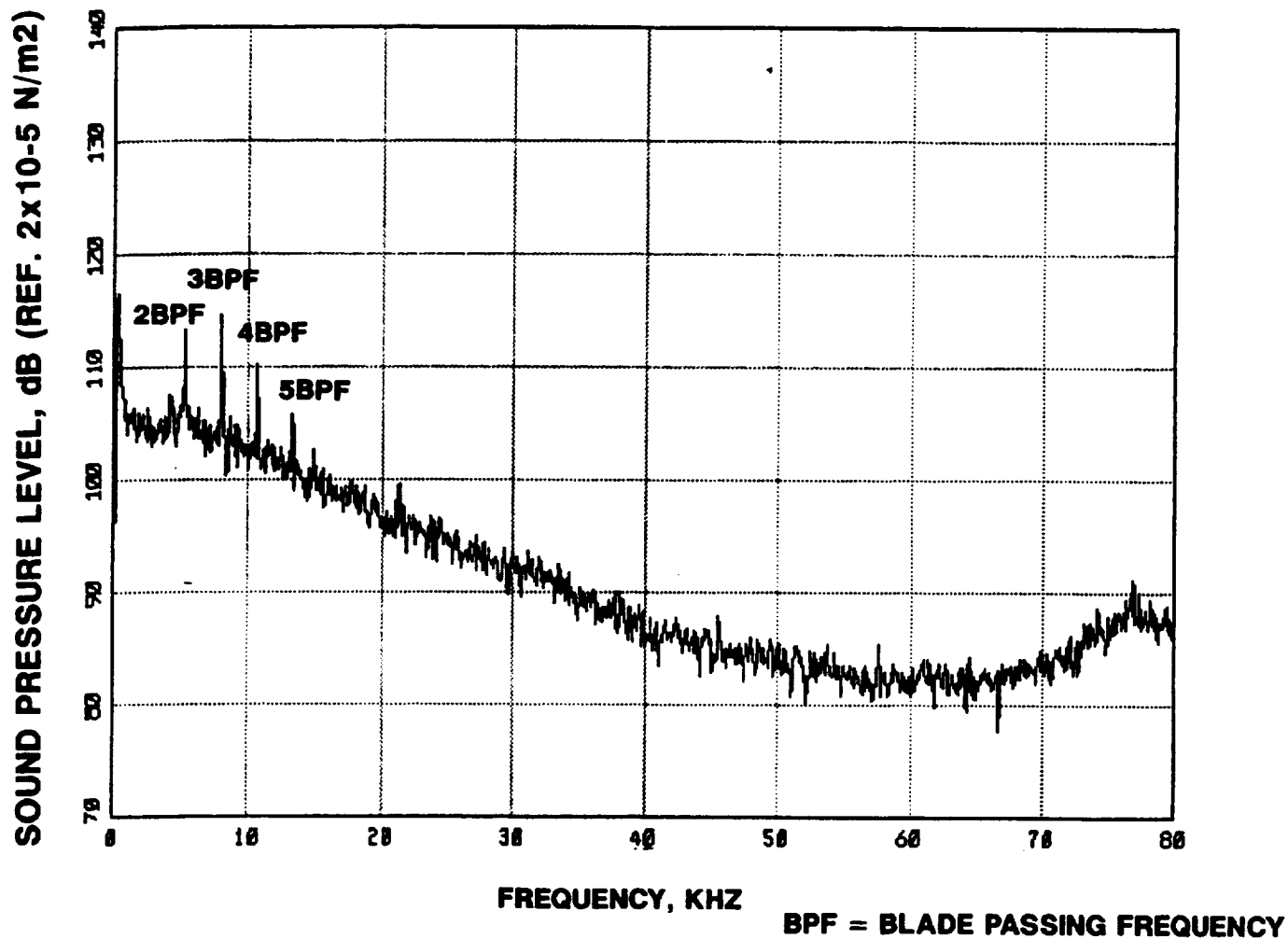
A. 0 - 8K SPECTRUM

FIGURE 8 CONTINUED

B. 0 - 80K SPECTRUM
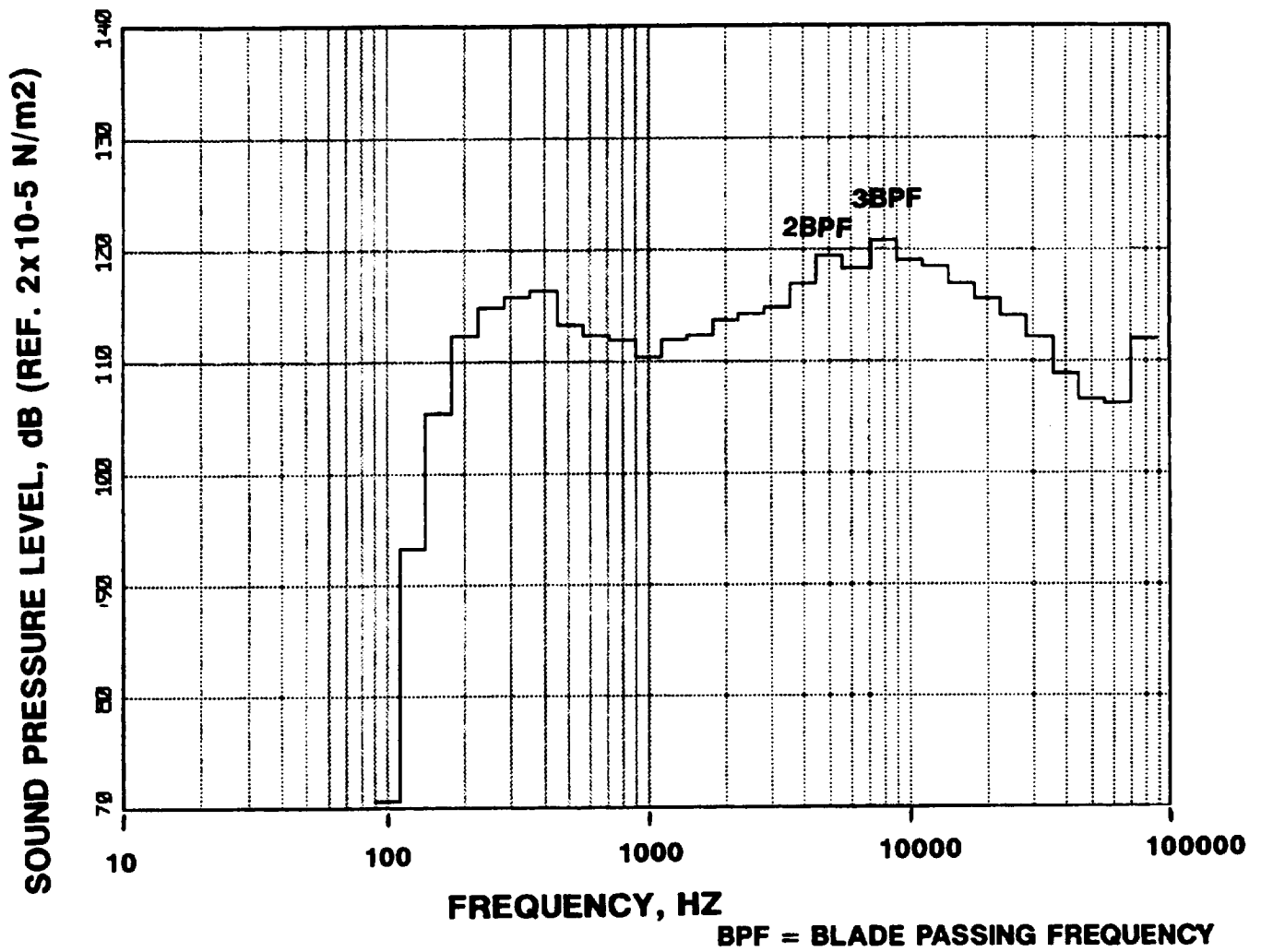
FIGURE 8 CONCLUDED

C. 1/3   OCTAVE SPECTRUM

23
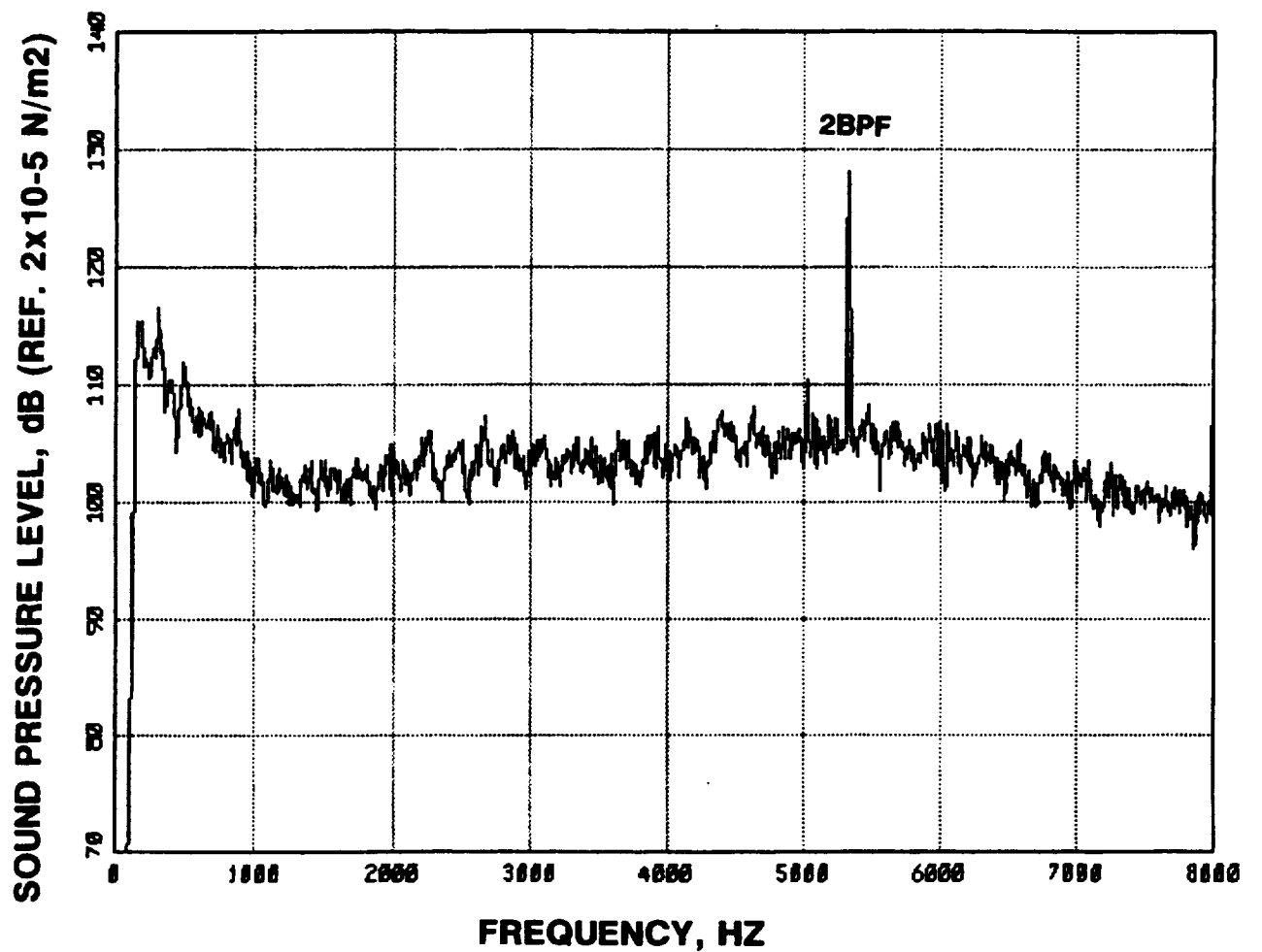
BPF = BLADE PASSING FREQUENCY

FIGURE 9   TAKEOFF SPEED, HARDWALL CONFIGURATION,
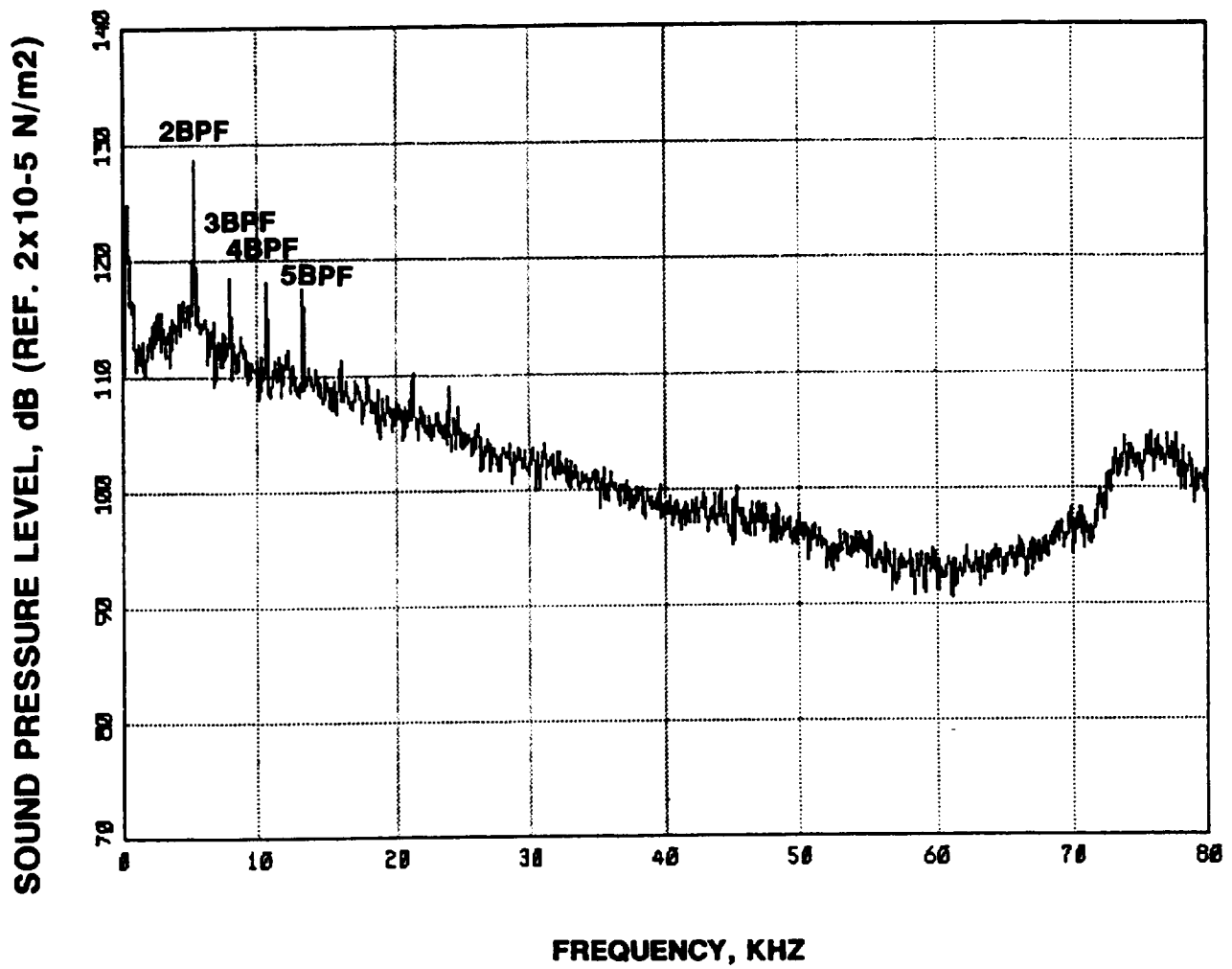
130 DEGREE ANGLE

A. 0 - 8K SPECTRUM

FIGURE 9 CONTINUED

B. 0 - 80K SPECTRUM
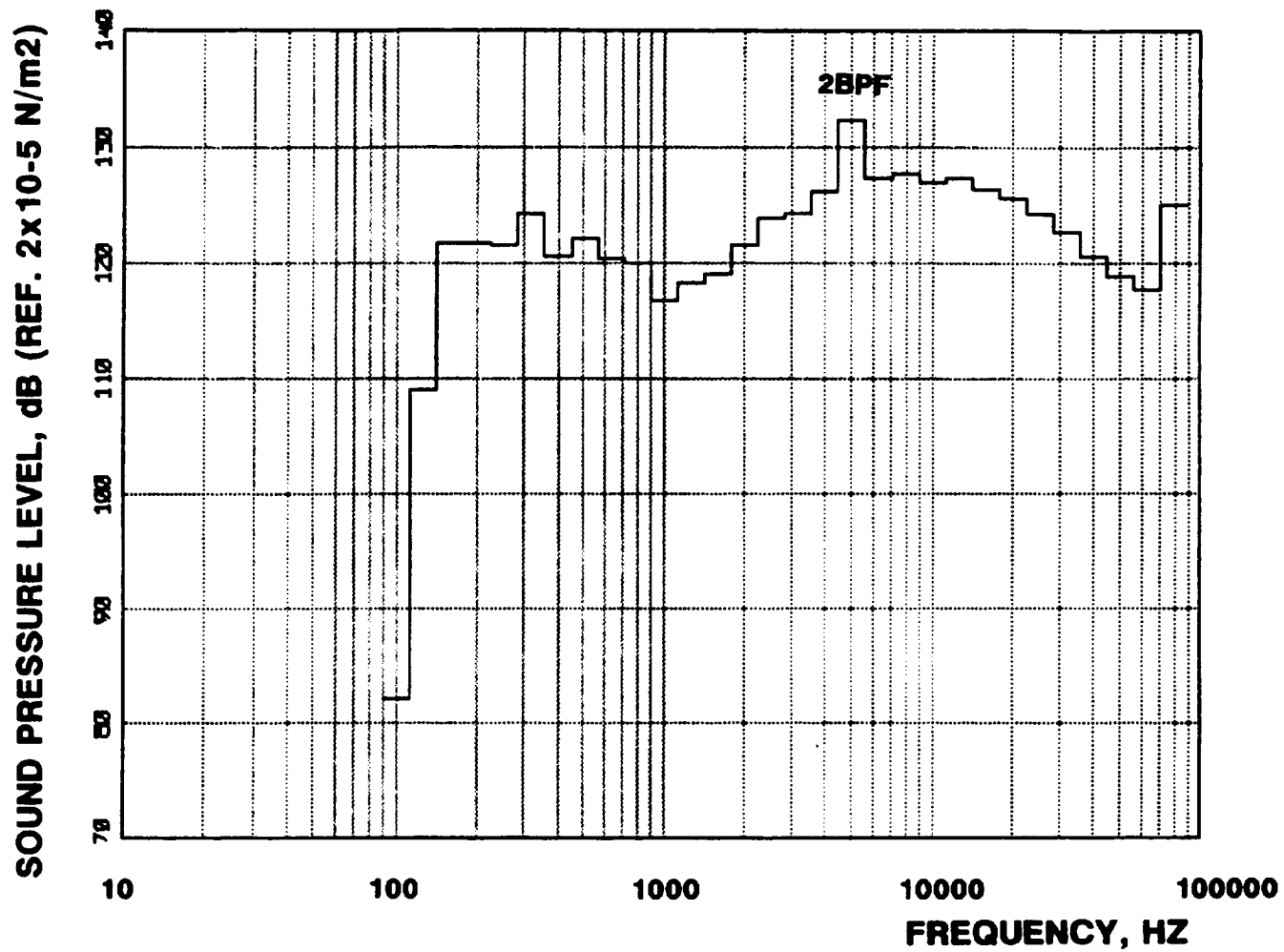
BPF = BLADE PASSING FREQUENCY

FIGURE 9 CONCLUDED

C. 1/3 OCTAVE SPECTRUM
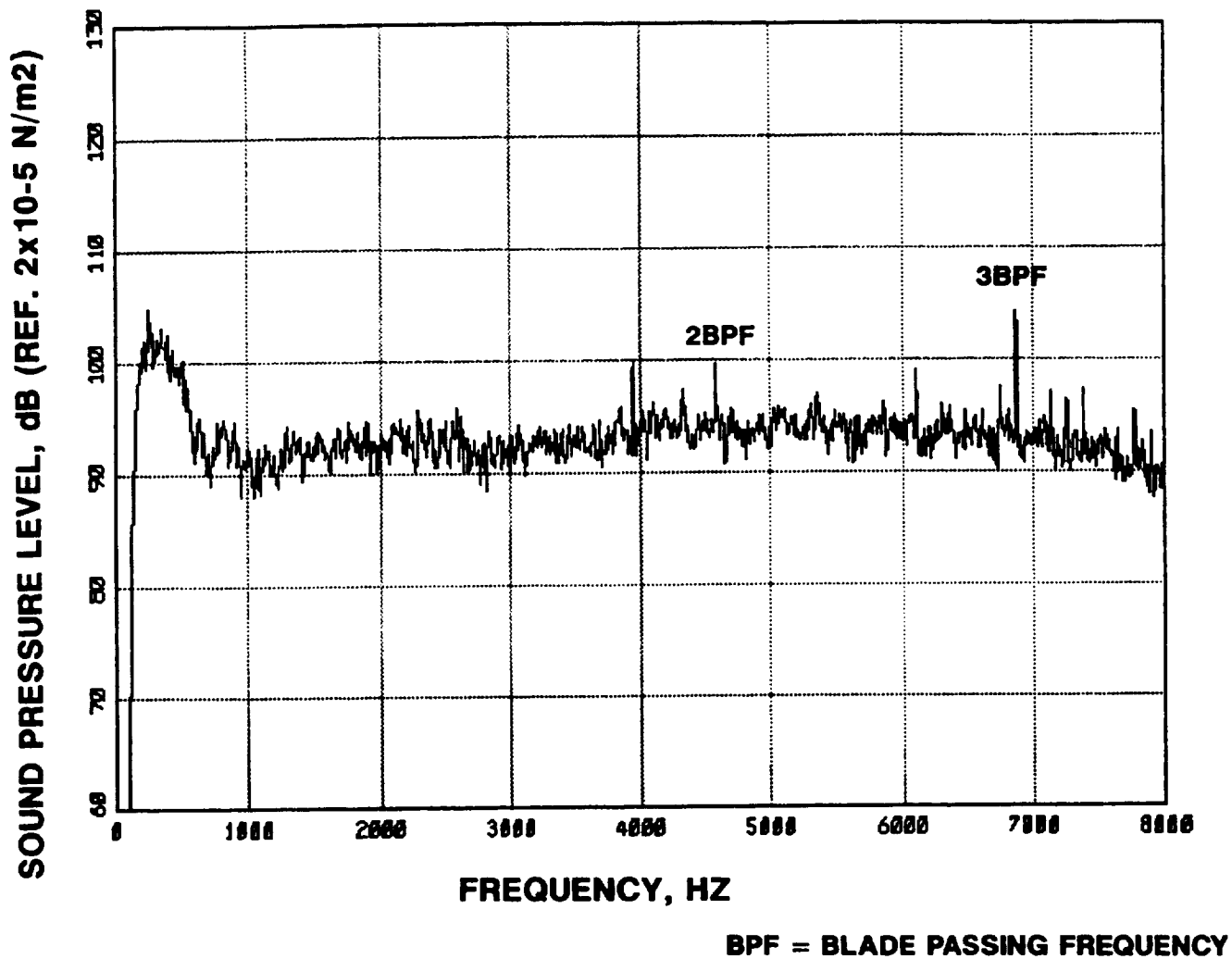
FIGURE 10 CUTBACK SPEED, HARDWALL CONFIGURATION,

50 DEGREE ANGLE

A. 0 - 8K SPECTRUM

BPF = BLADE PASSING FREQUENCY
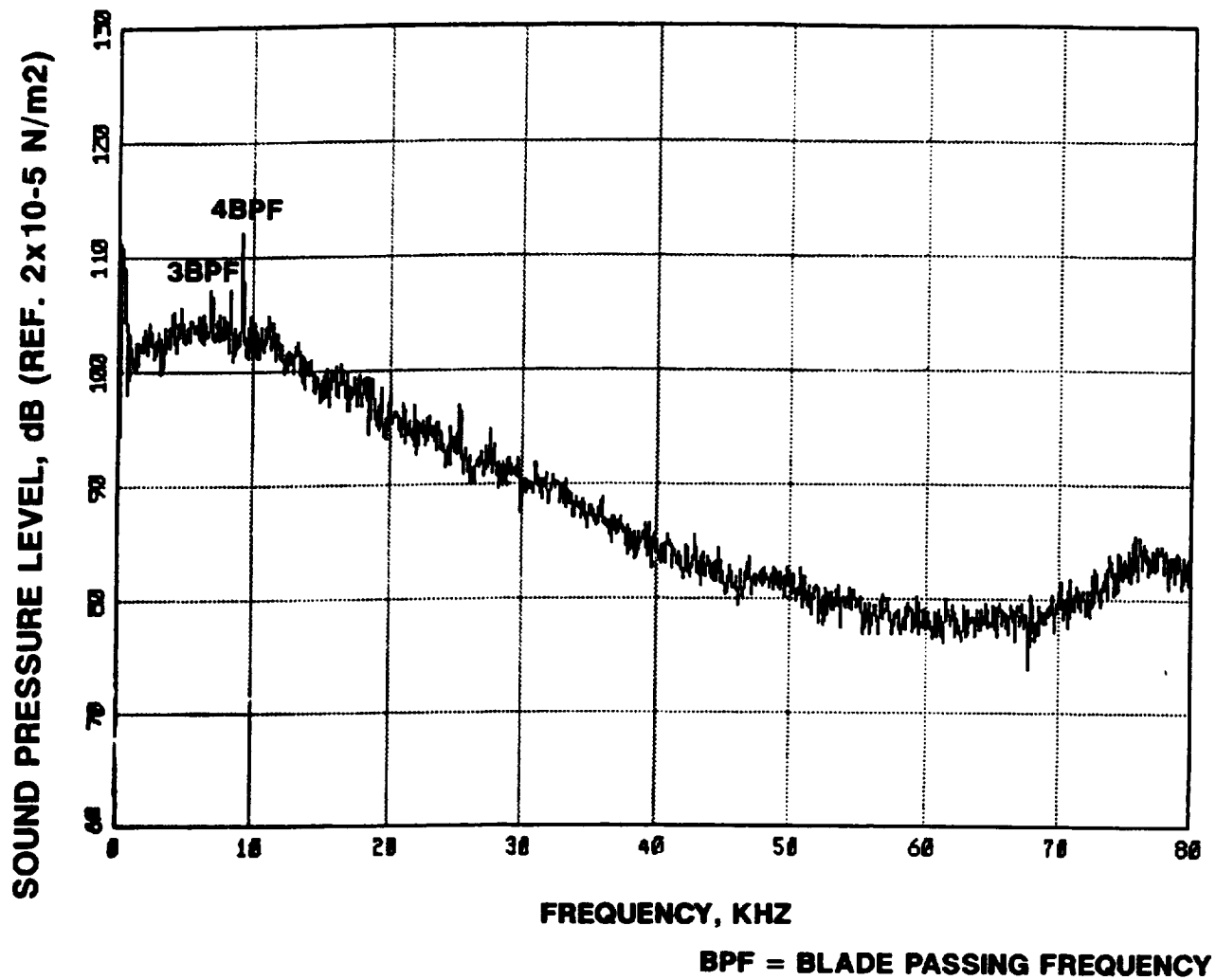
FIGURE 10 CONTINUED

B. 0 - 80K SPECTRUM
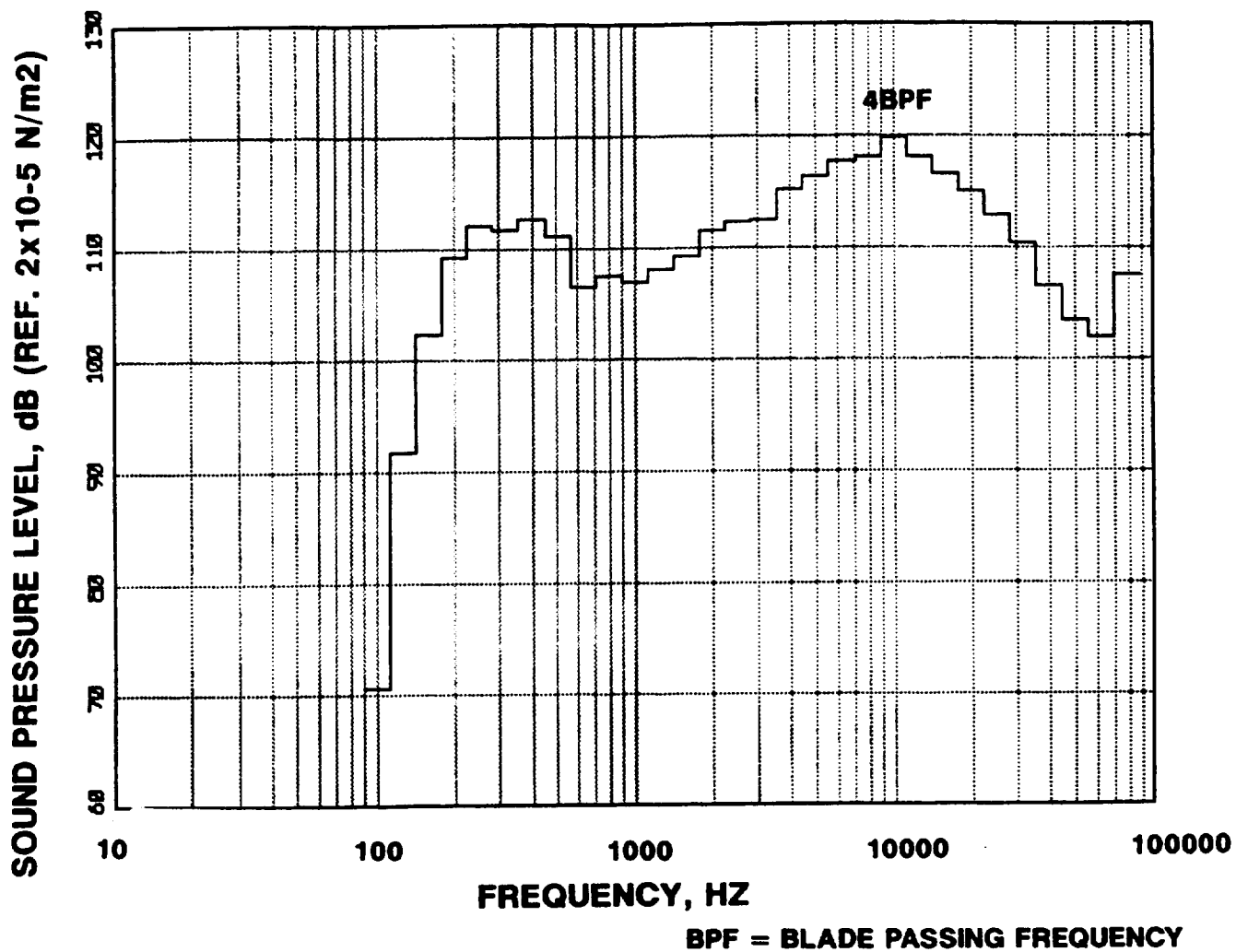
FIGURE 10 CONCLUDED

C. 1/3 OCTAVE SPECTRUM
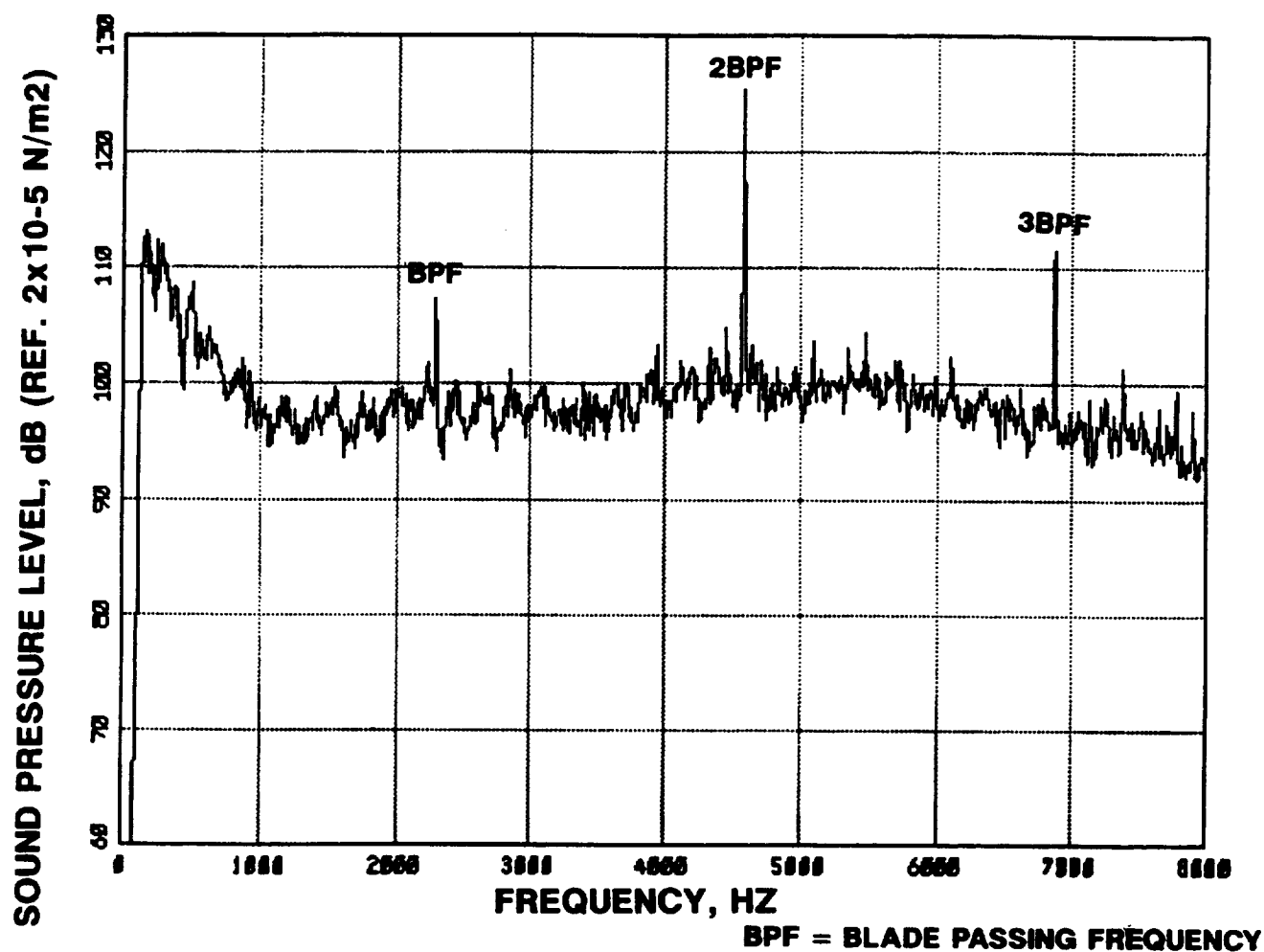
FIGURE 11 CUTBACK SPEED, HARDWALL CONFIGURATION,

130 DEGREE ANGLE
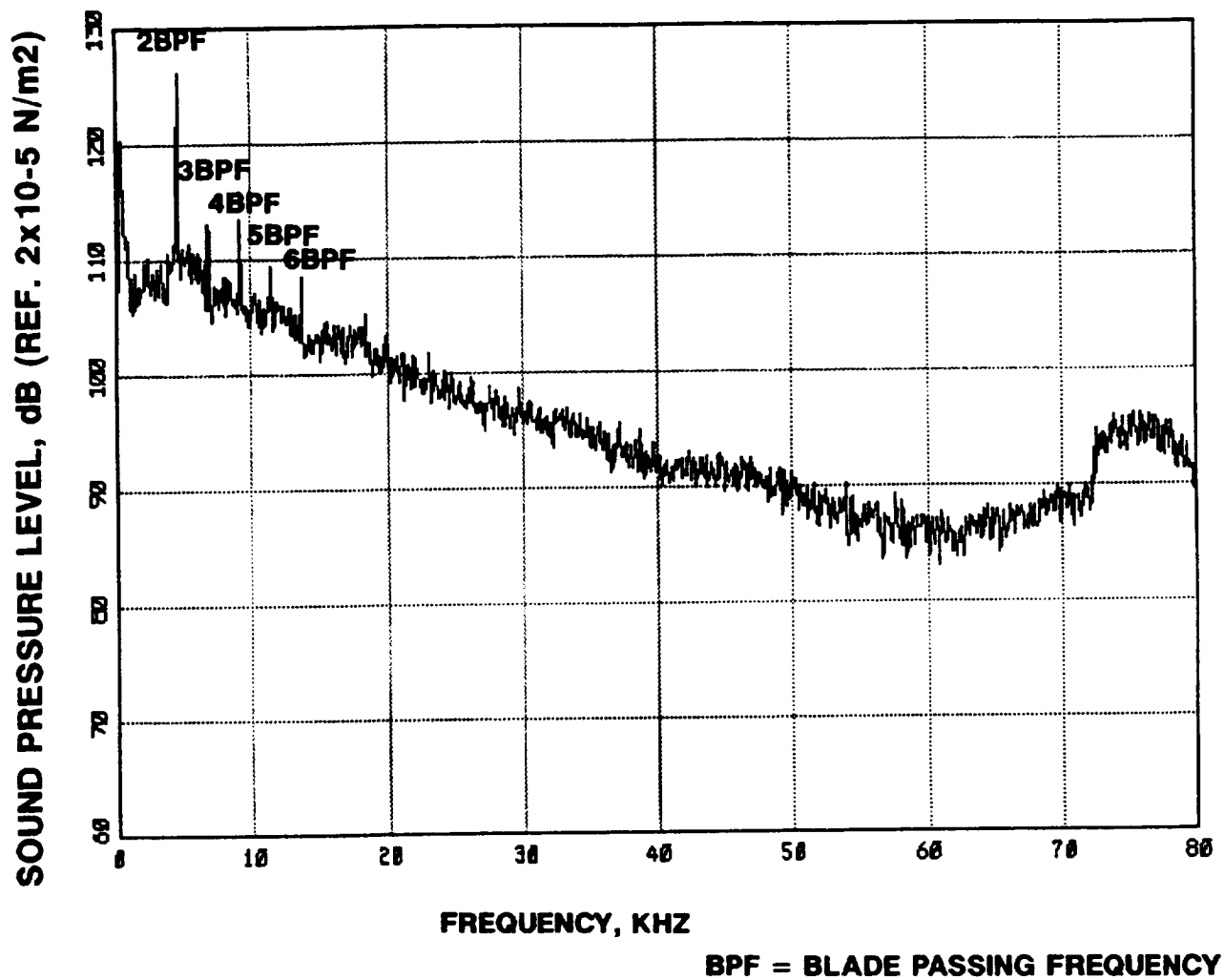
A. 0 - 8K SPECTRUM

FIGURE 11 CONTINUED

B. 0 - 80K SPECTRUM

31
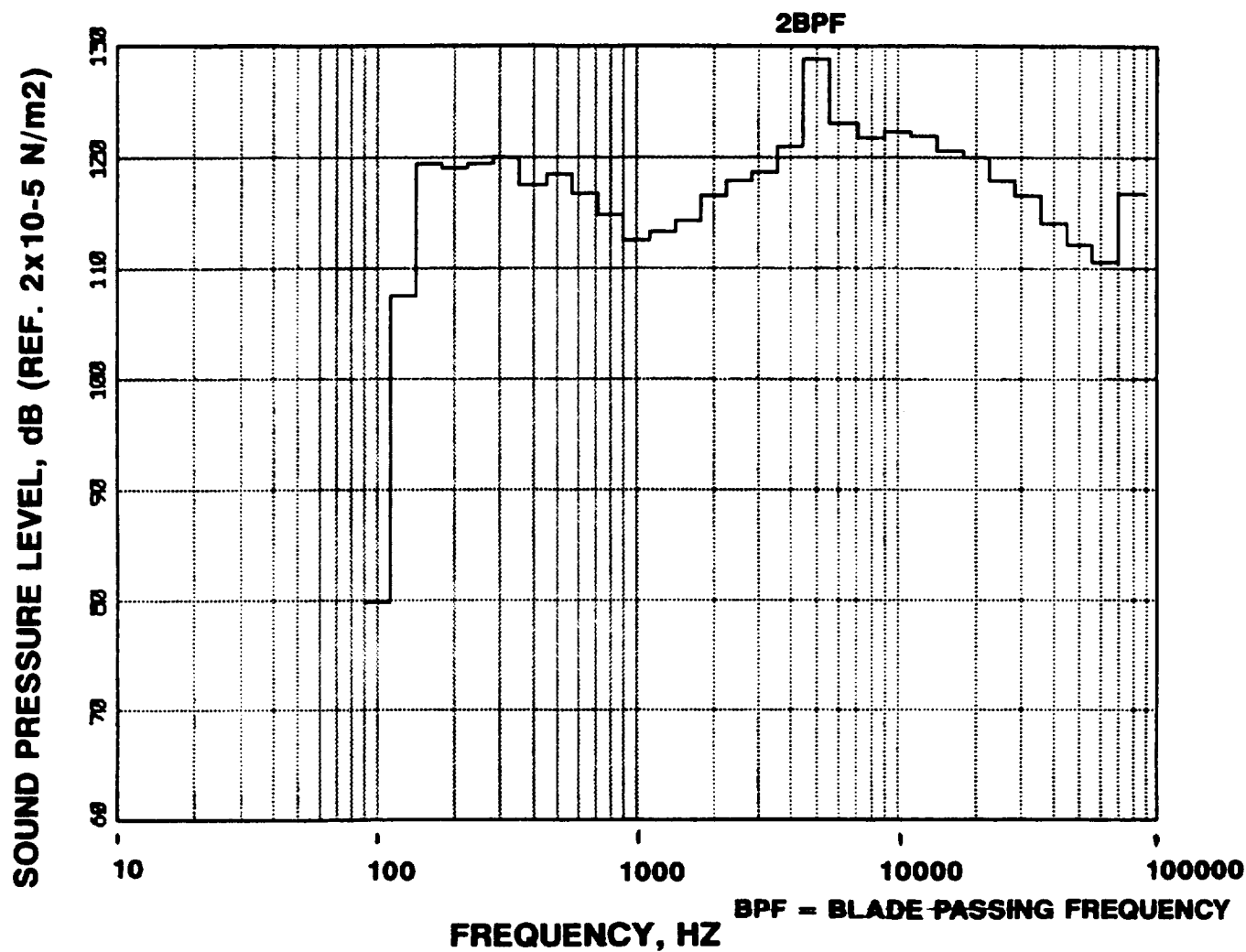
FIGURE 11 CONCLUDED

C. 1/3 OCTAVE SPECTRUM
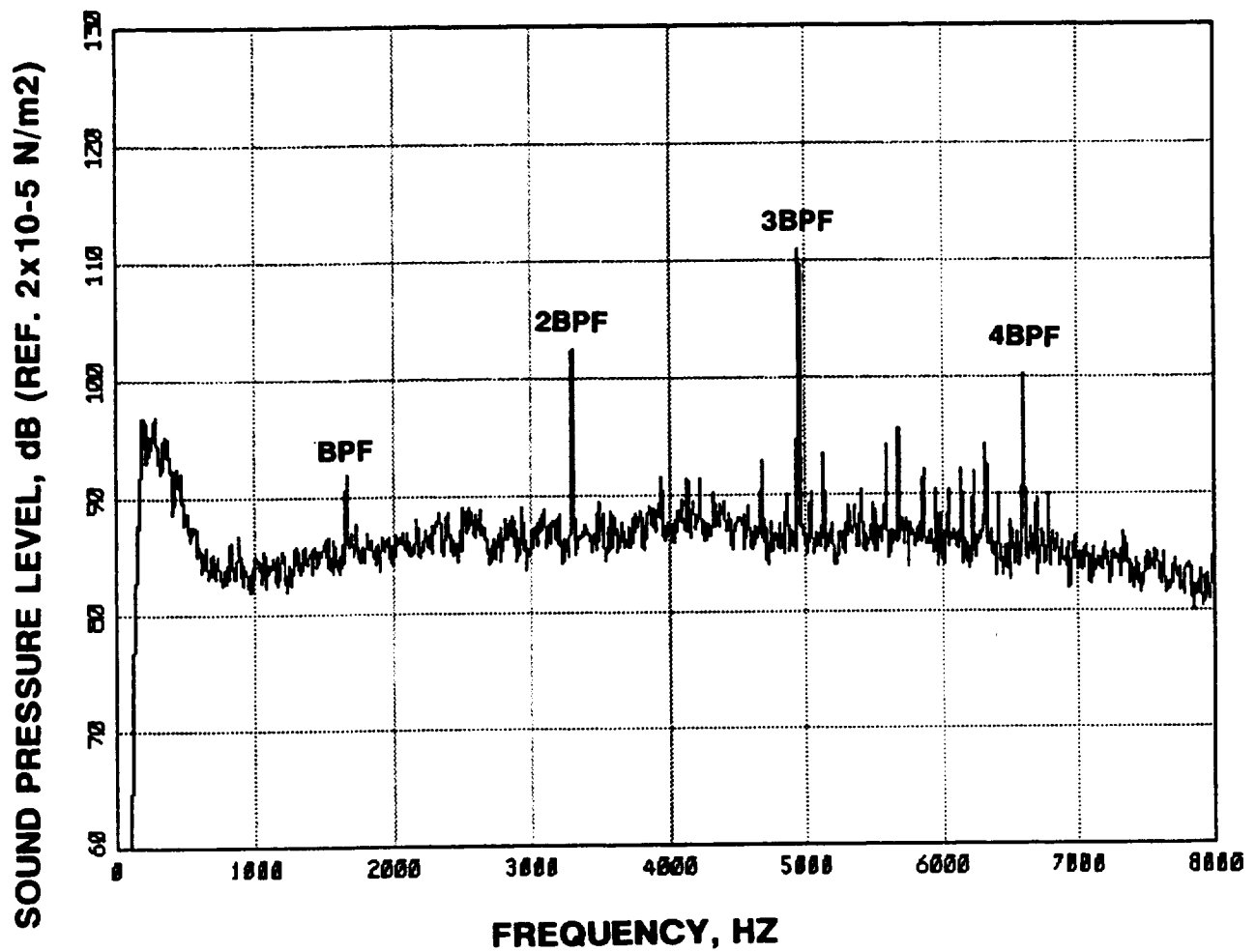
FIGURE 12 APPROACH SPEED, HARDWALL CONFIGURATION,

50 DEGREE ANGLE

A. 0 - 8K   SPECTRUM

33
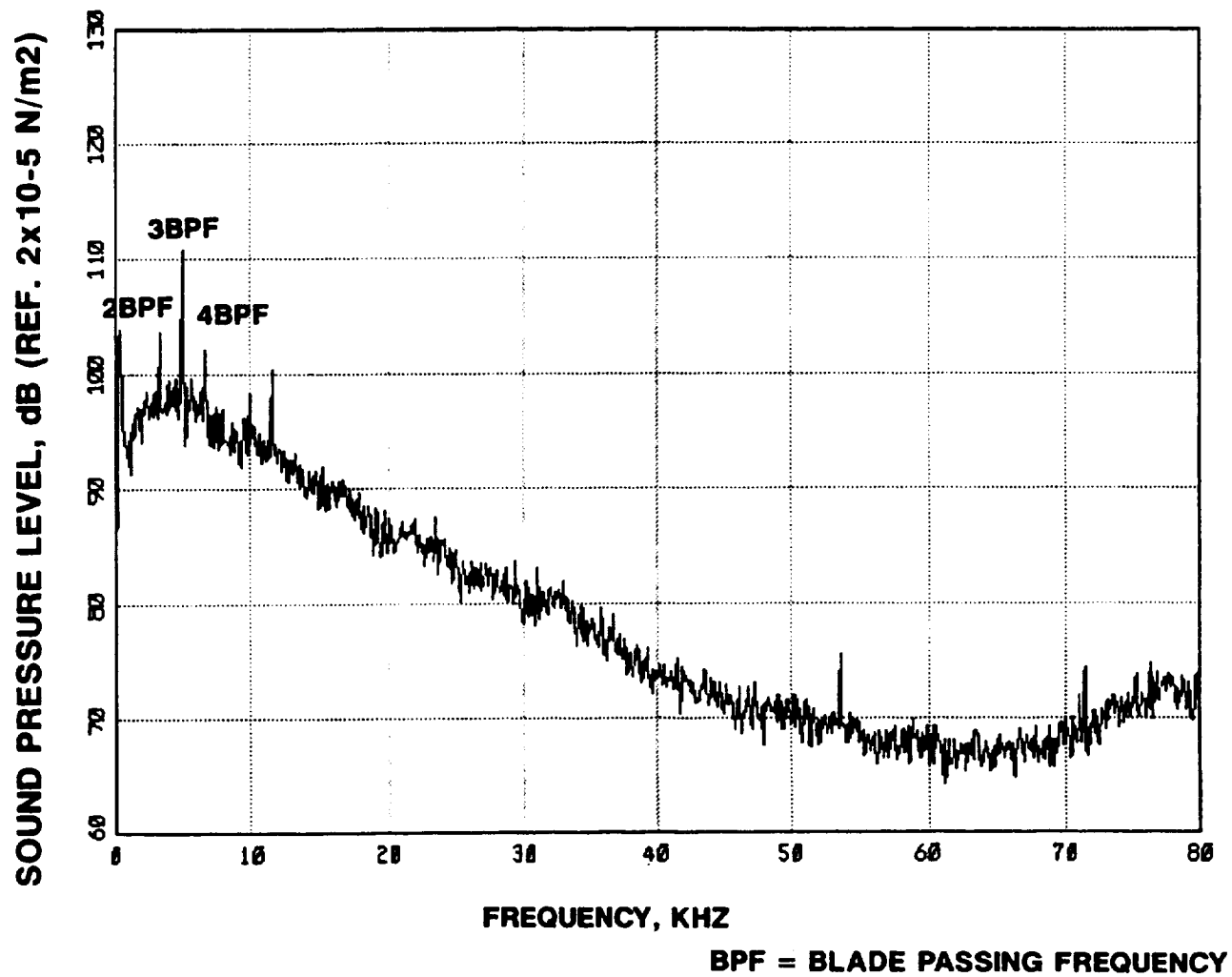
FIGURE 12 CONTINUED

B. 0 - 80K SPECTRUM
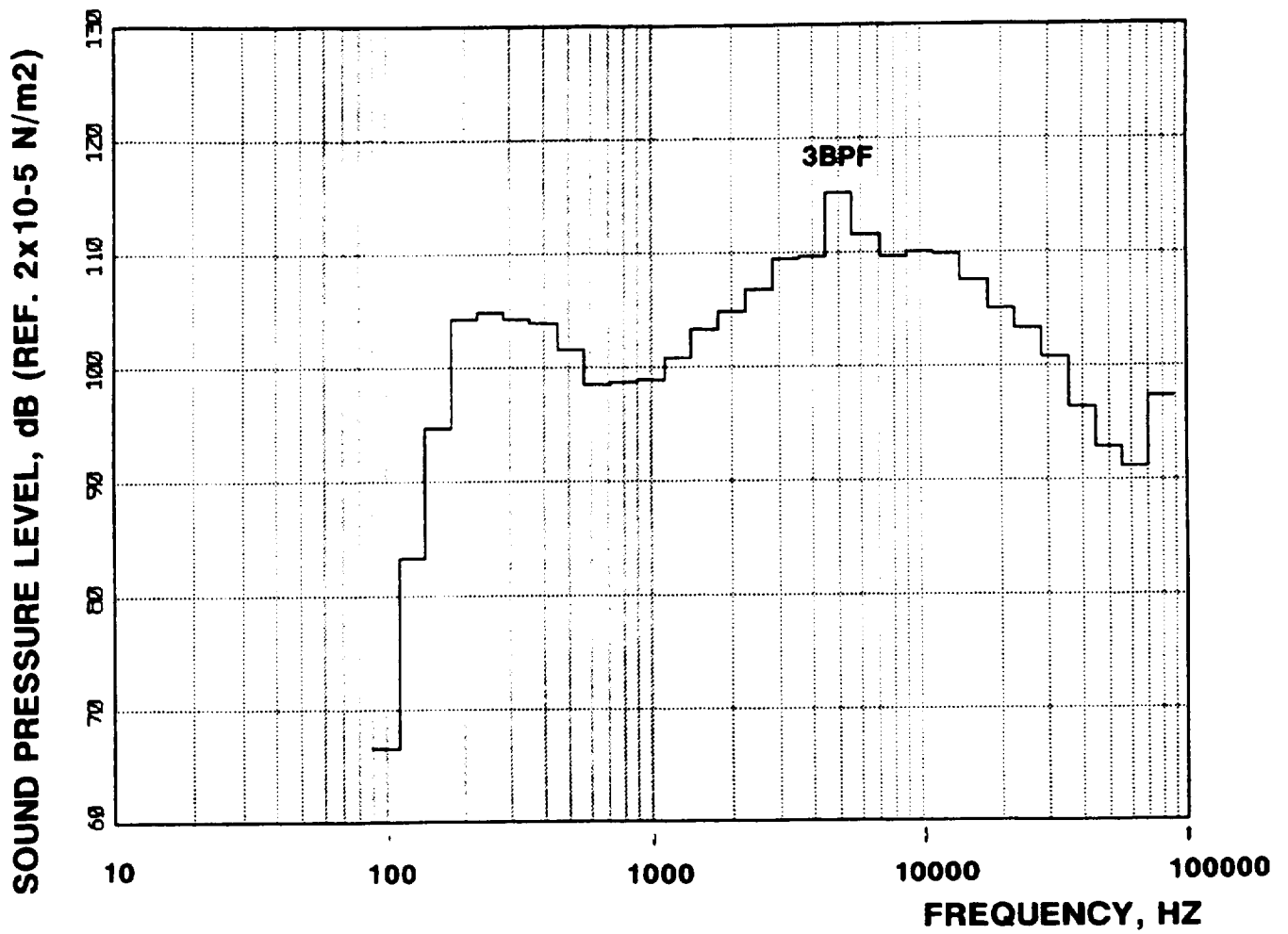
FIGURE 12 CONCLUDED

BPF = BLADE PASSING FREQUENCY

C. 1/3 OCTAVE SPECTRUM
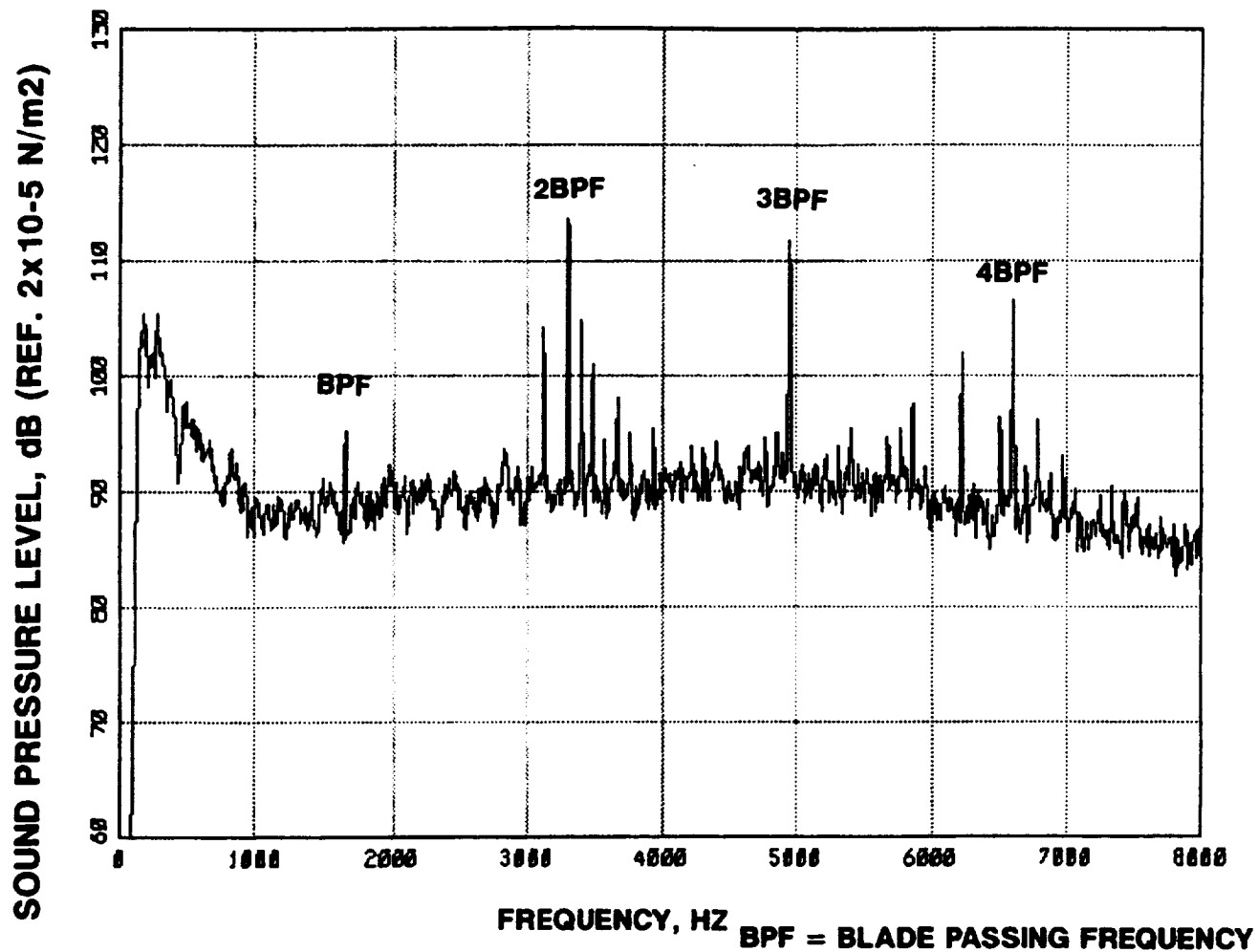
FIGURE 13 APPROACH SPEED, HARDWALL CONFIGURATION,

130 DEGREE ANGLE

A. 0 - 8K   SPECTRUM

BPF = BLADE PASSING FREQUENCY
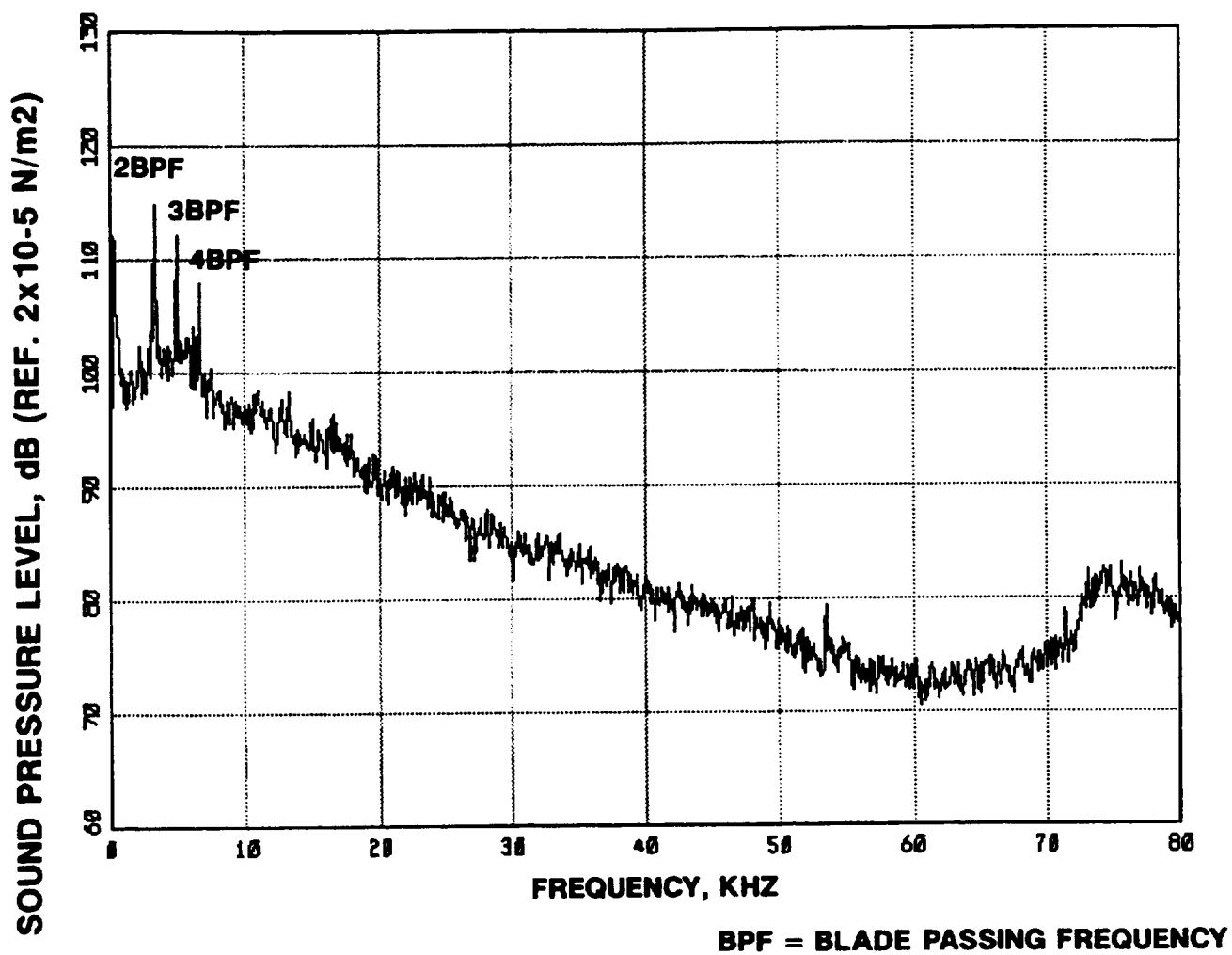
FIGURE 13 CONTINUED

B. 0 - 80K SPECTRUM

37
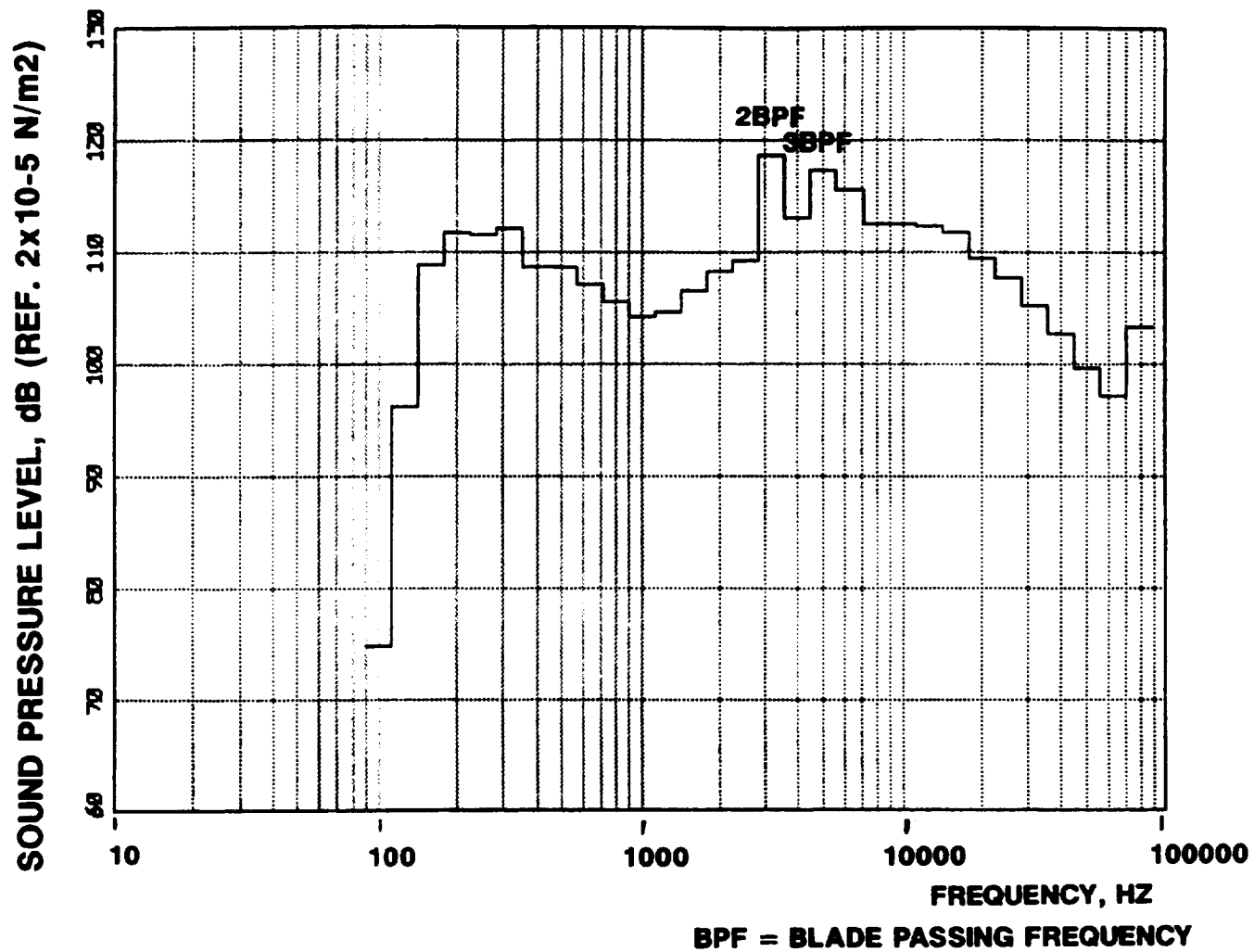
FIGURE 13 CONCLUDED

C. 1/3 OCTAVE SPECTRUM
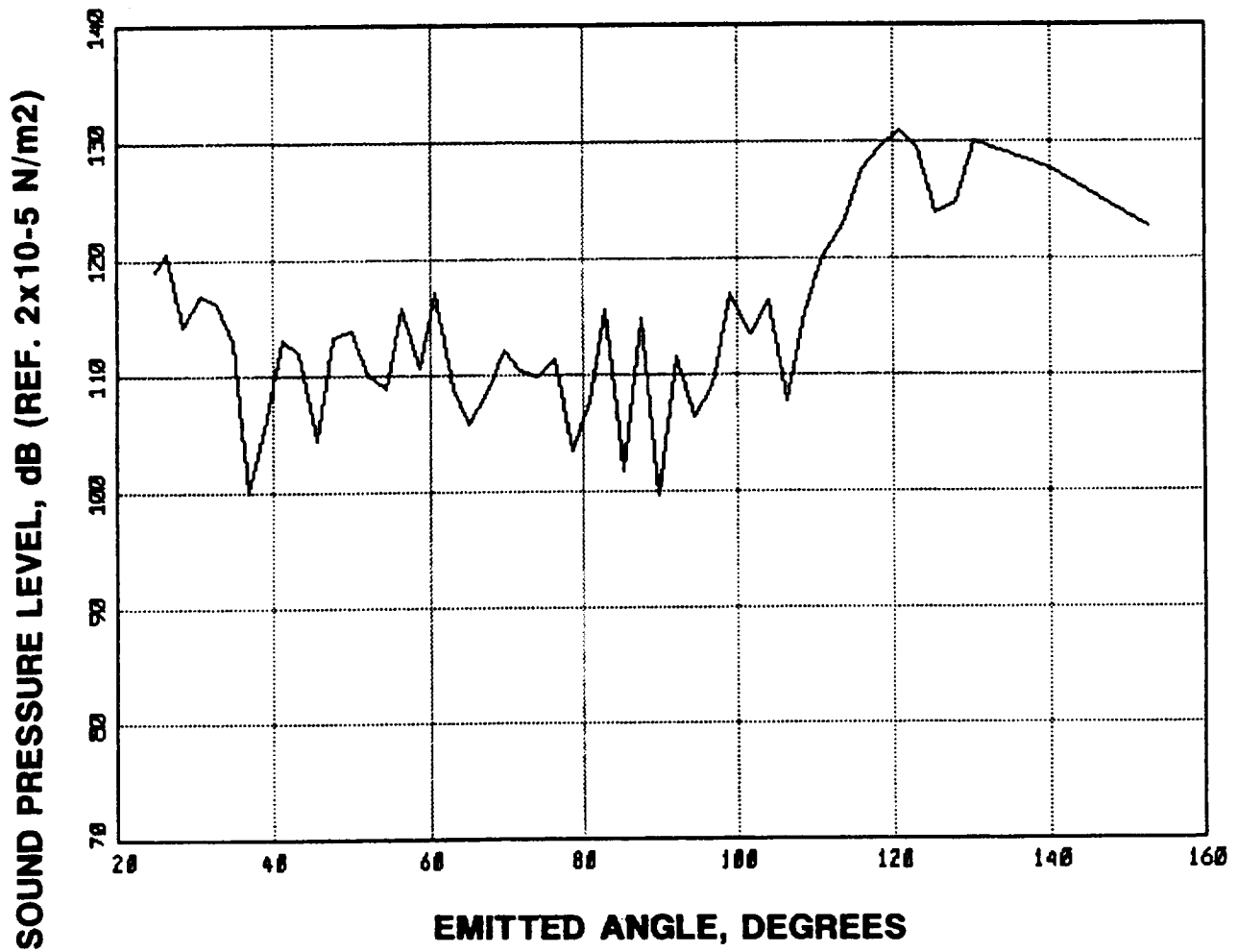
FIGURE 14 DIRECTIVITY OF TONE AT TWICE BLADE PASSING FREQUENCY, HARDWALL CONFIGURATION
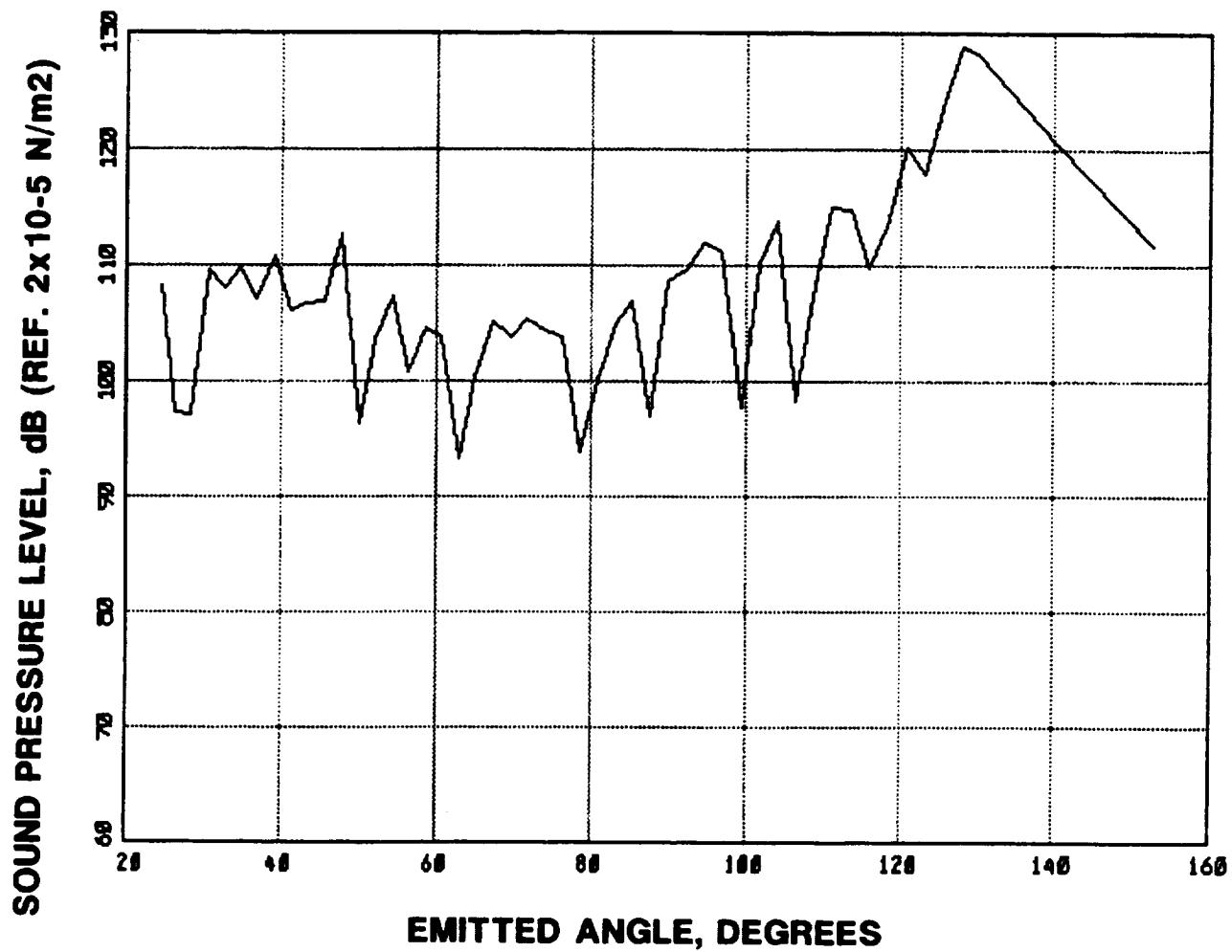
A. TAKEOFF SPEED

FIGURE 14 CONTINUED

B. CUTBACK SPEED

40
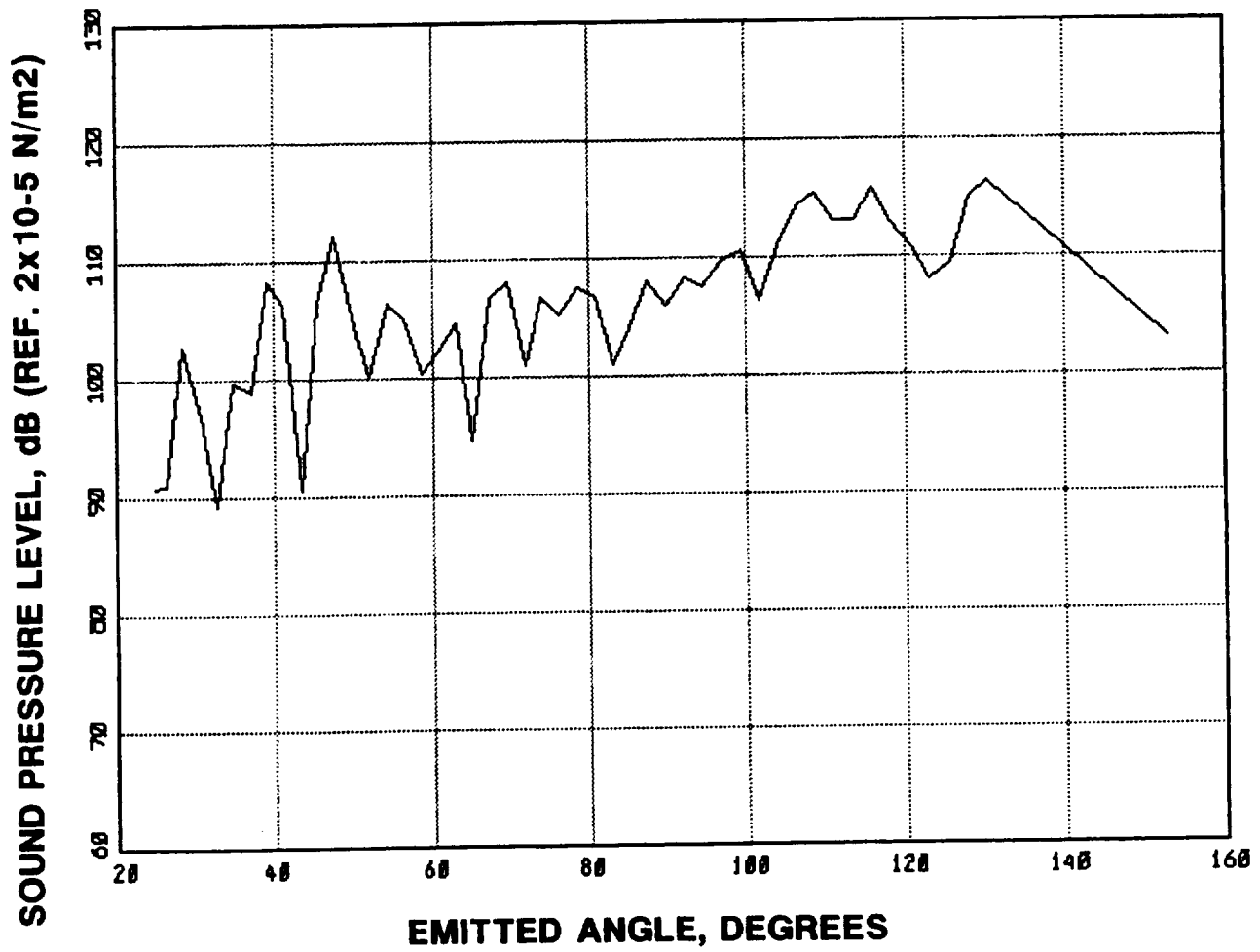
FIGURE 14 CONCLUDED

C. APPROACH SPEED
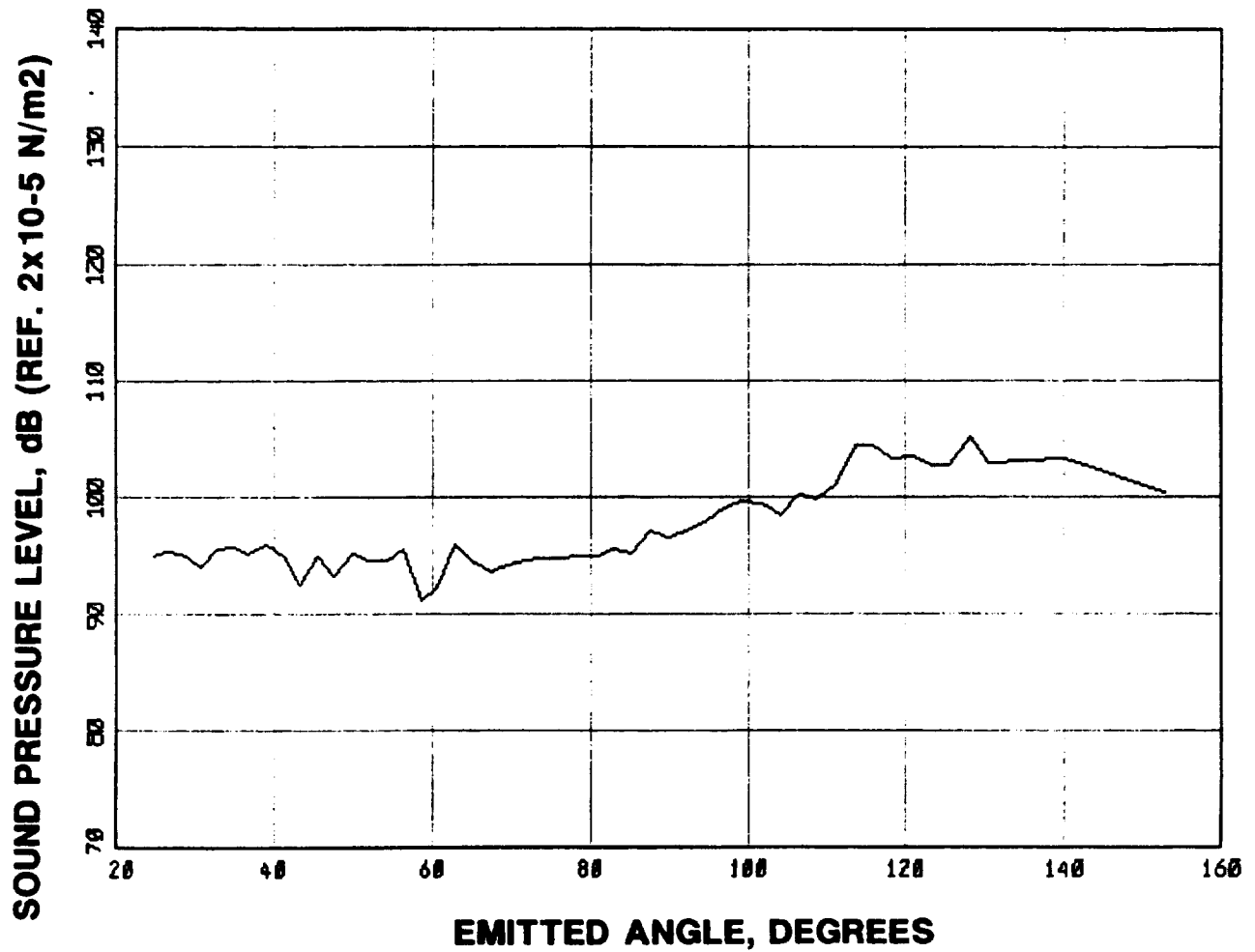
FIGURE 15 DIRECTIVITY OF BROADBAND NOISE AT 6000 HZ,

HARDWALL CONFIGURATION

A. TAKEOFF SPEED

42
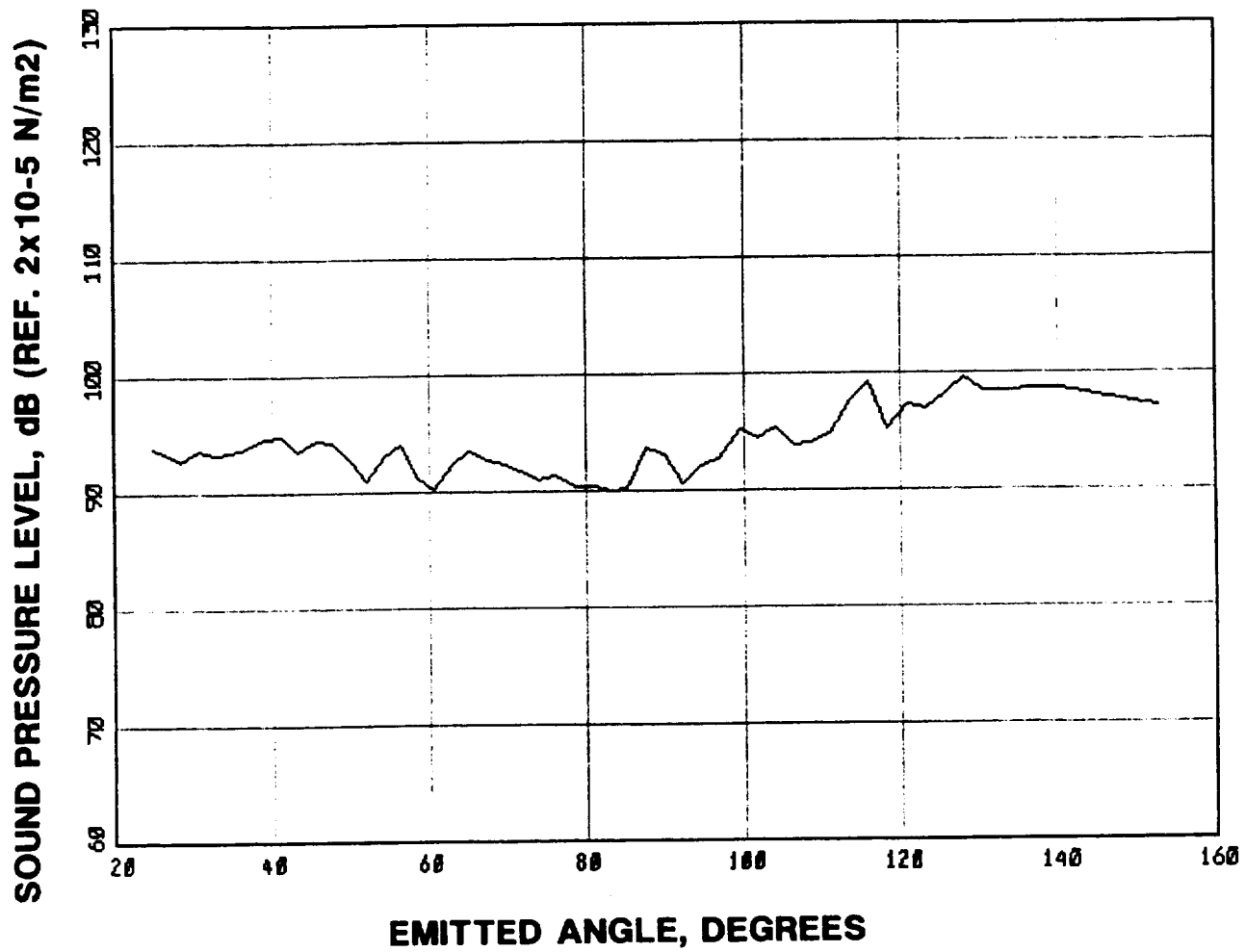
FIGURE 15 CONCLUDED

B. CUTBACK SPEED
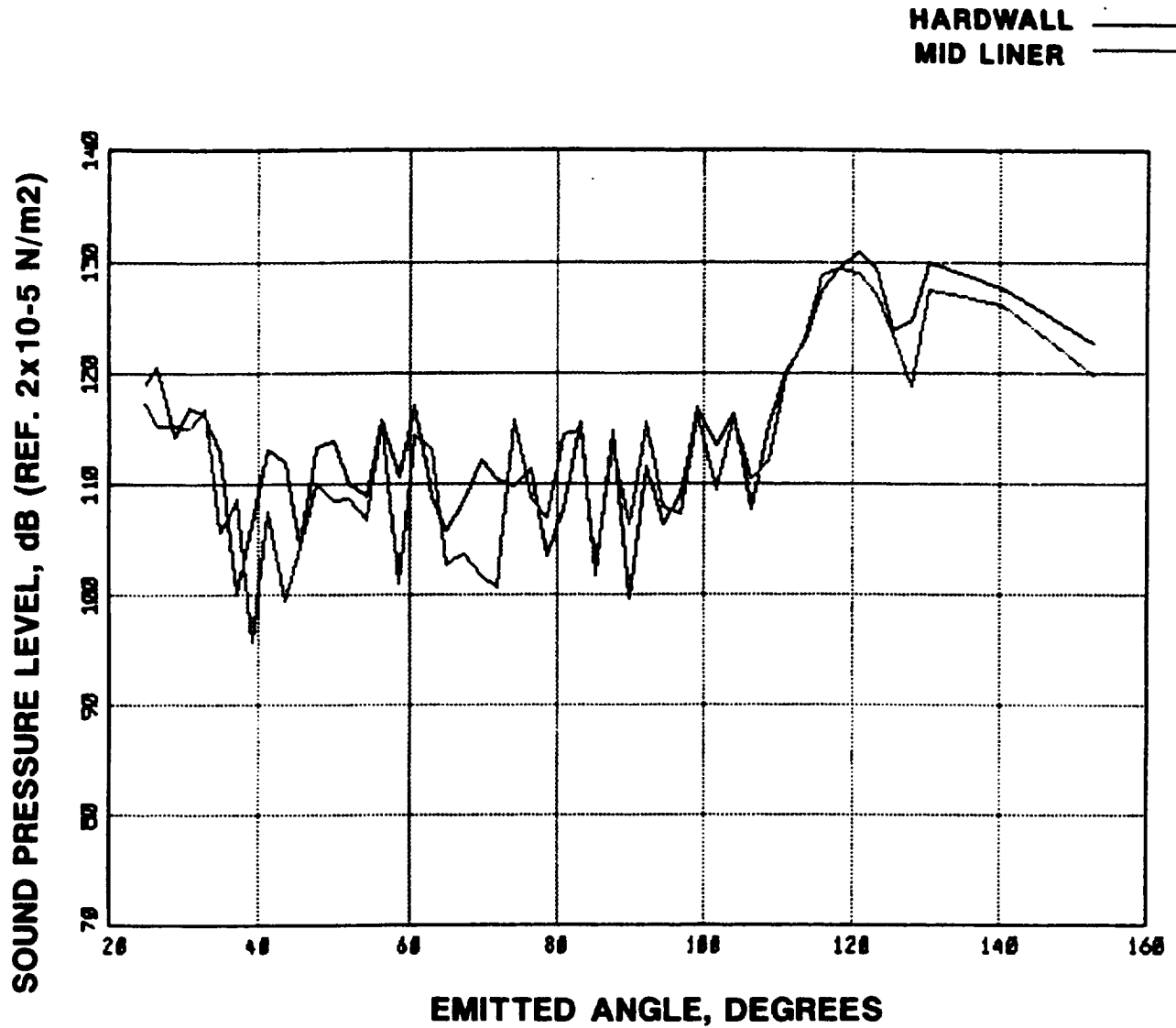
FIGURE 16   2 BPF TONE DIRECTIVITY AT TAKEOFF

A. HARDWALL AND MID LINER
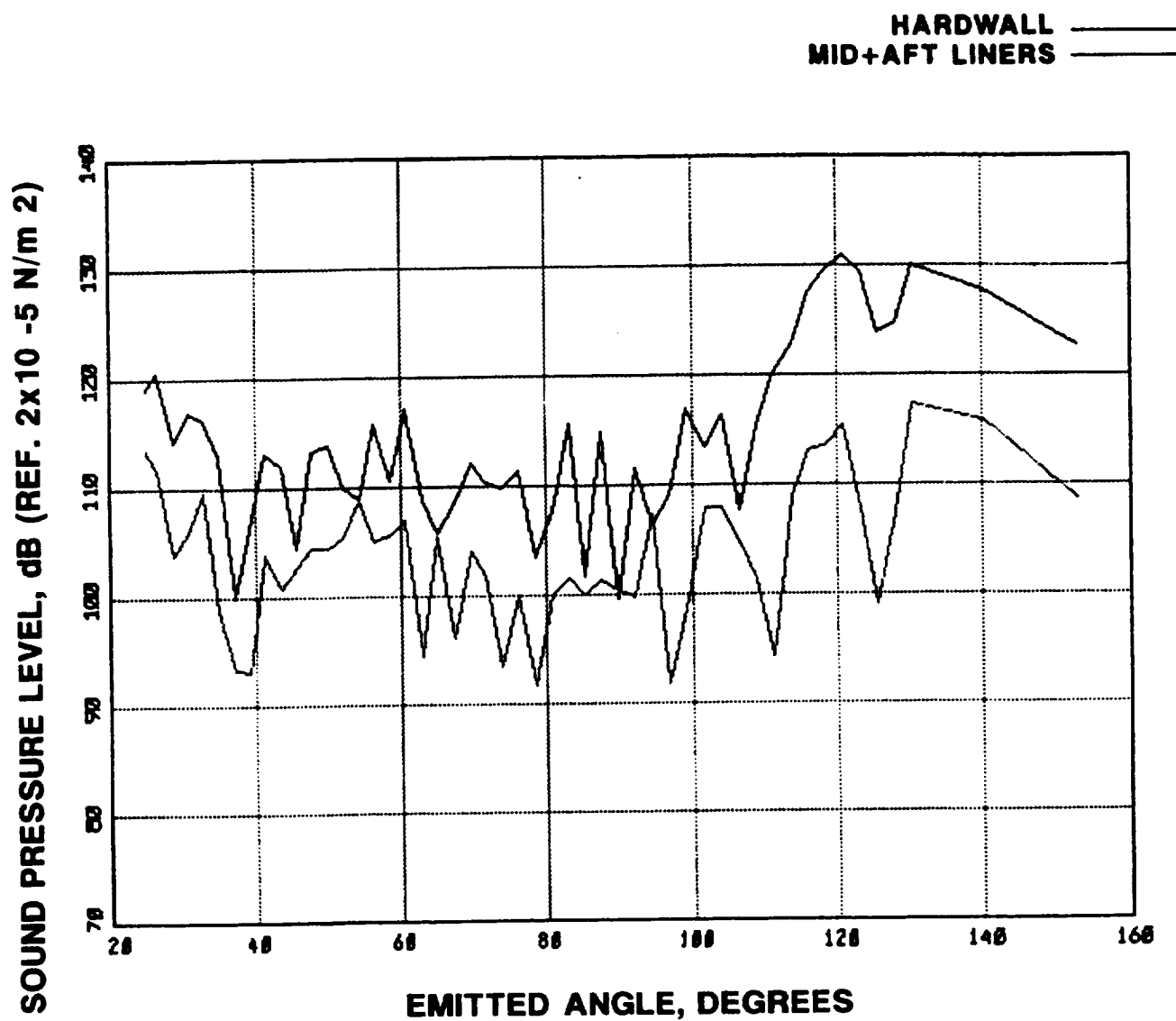
FIGURE 16   2 BPF TONE DIRECTIVITY AT TAKEOFF

B. HARDWALL AND MID+AFT LINERS
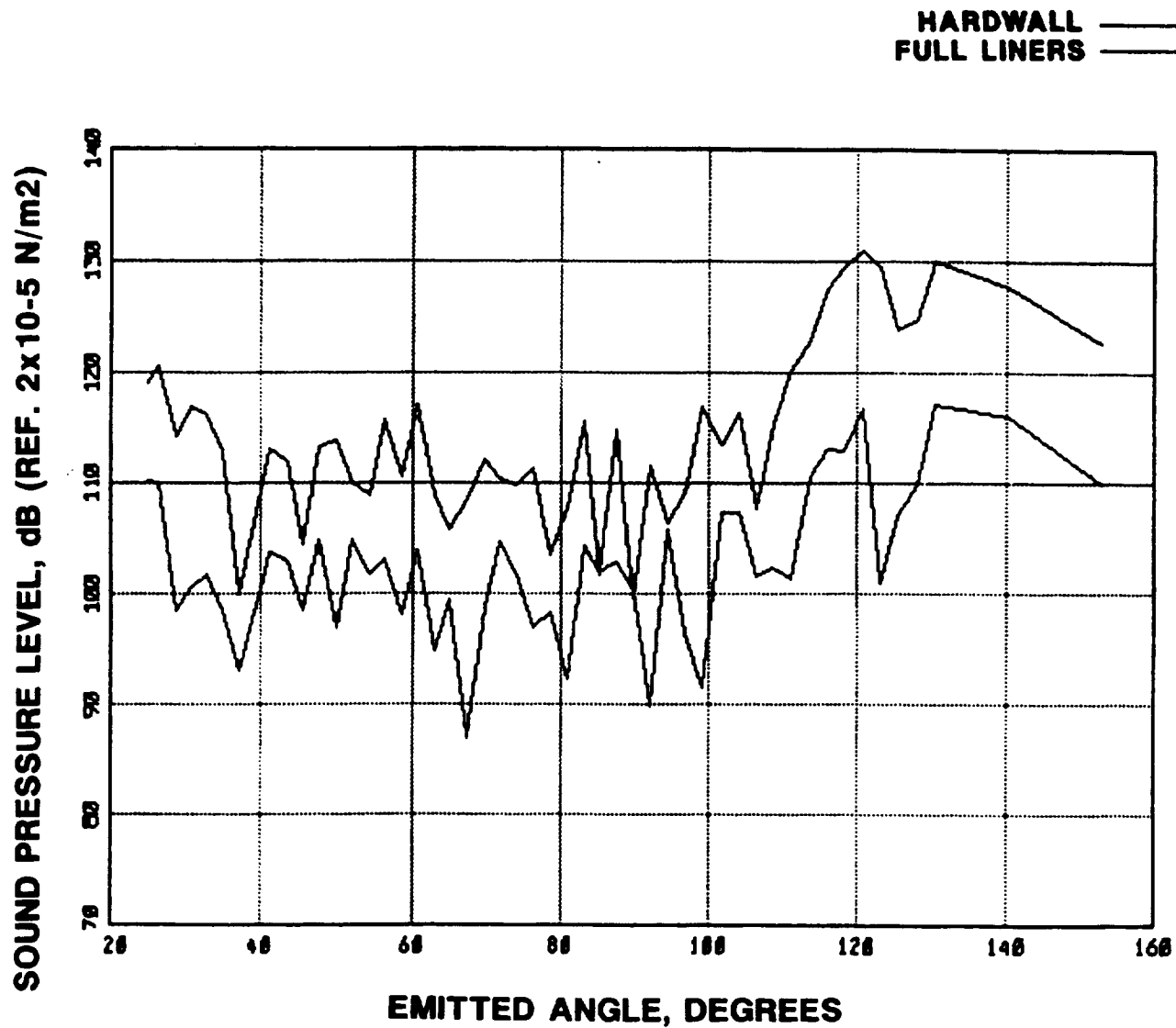
FIGURE 16 2 BPF TONE DIRECTIVITY AT TAKEOFF

C. HARDWALL AND FULL LINERS

46
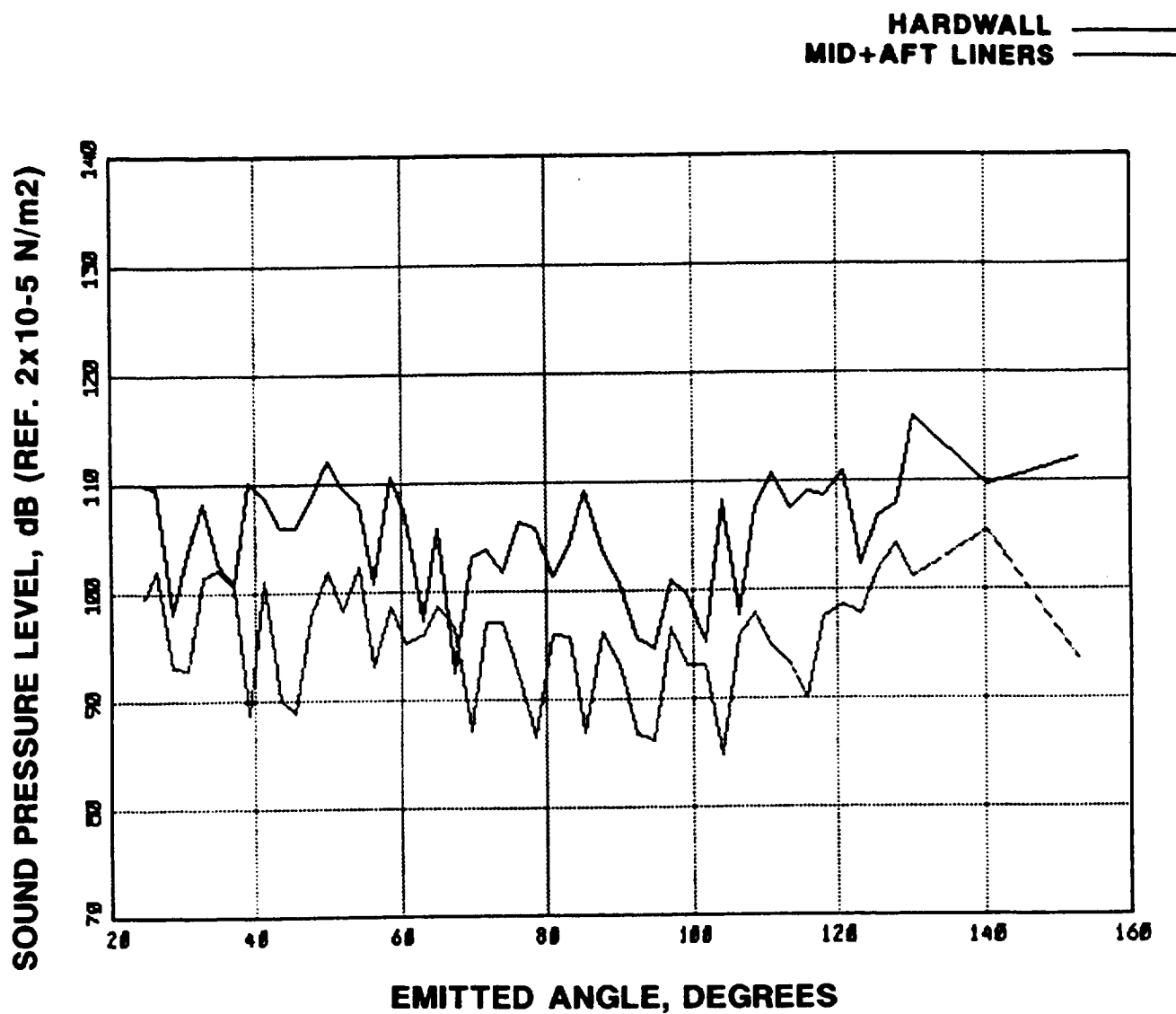
FIGURE 17   3 BPF TONE DIRECTIVITY AT TAKEOFF

HARDWALL AND MID+AFT LINERS

EMITTED ANGLE, DEGREES
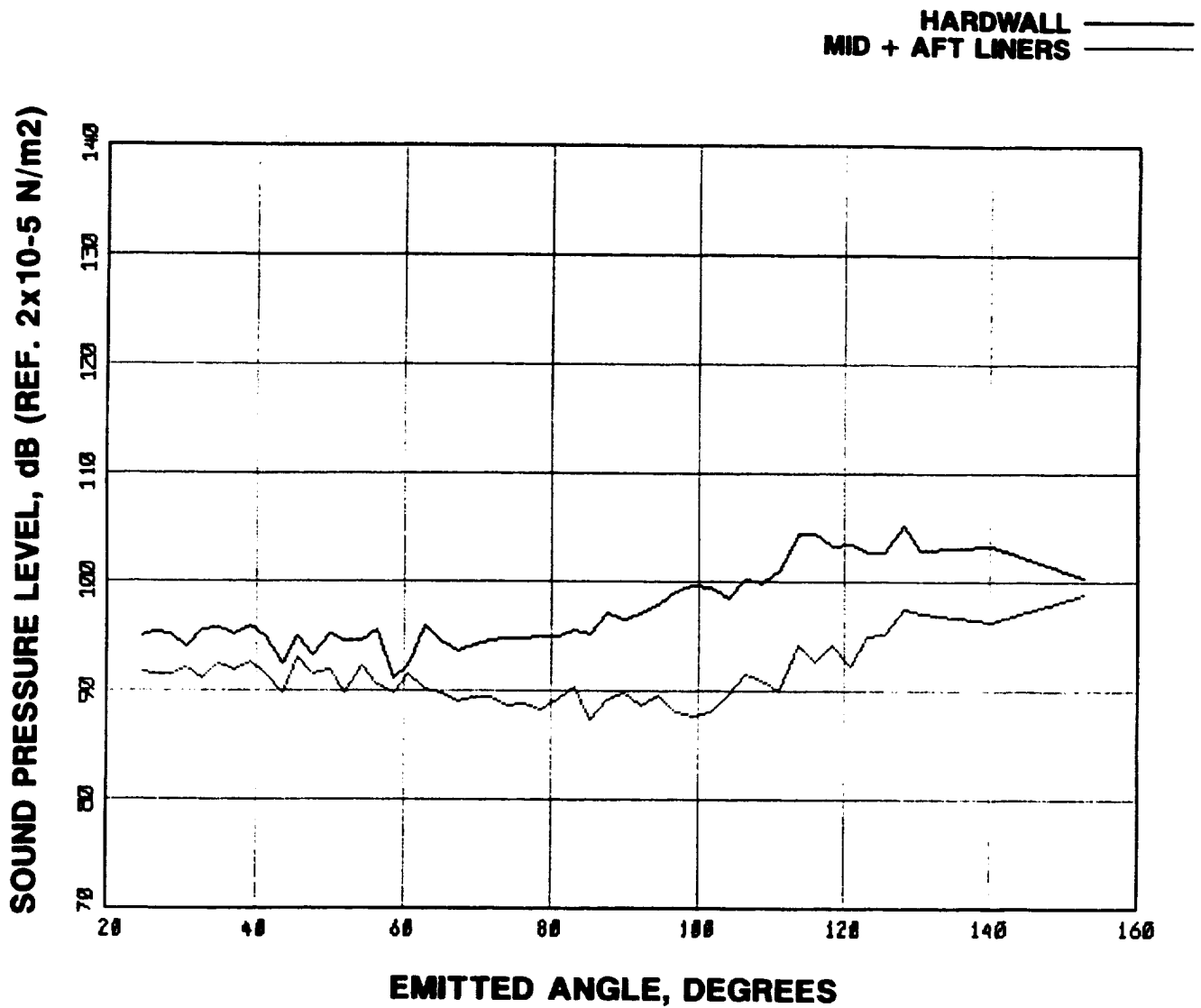
FIGURE 18 BROADBAND DIRECTIVITY AT 6000 HZ,

TAKEOFF SPEED

HARDWALL AND MID + AFT LINERS

48
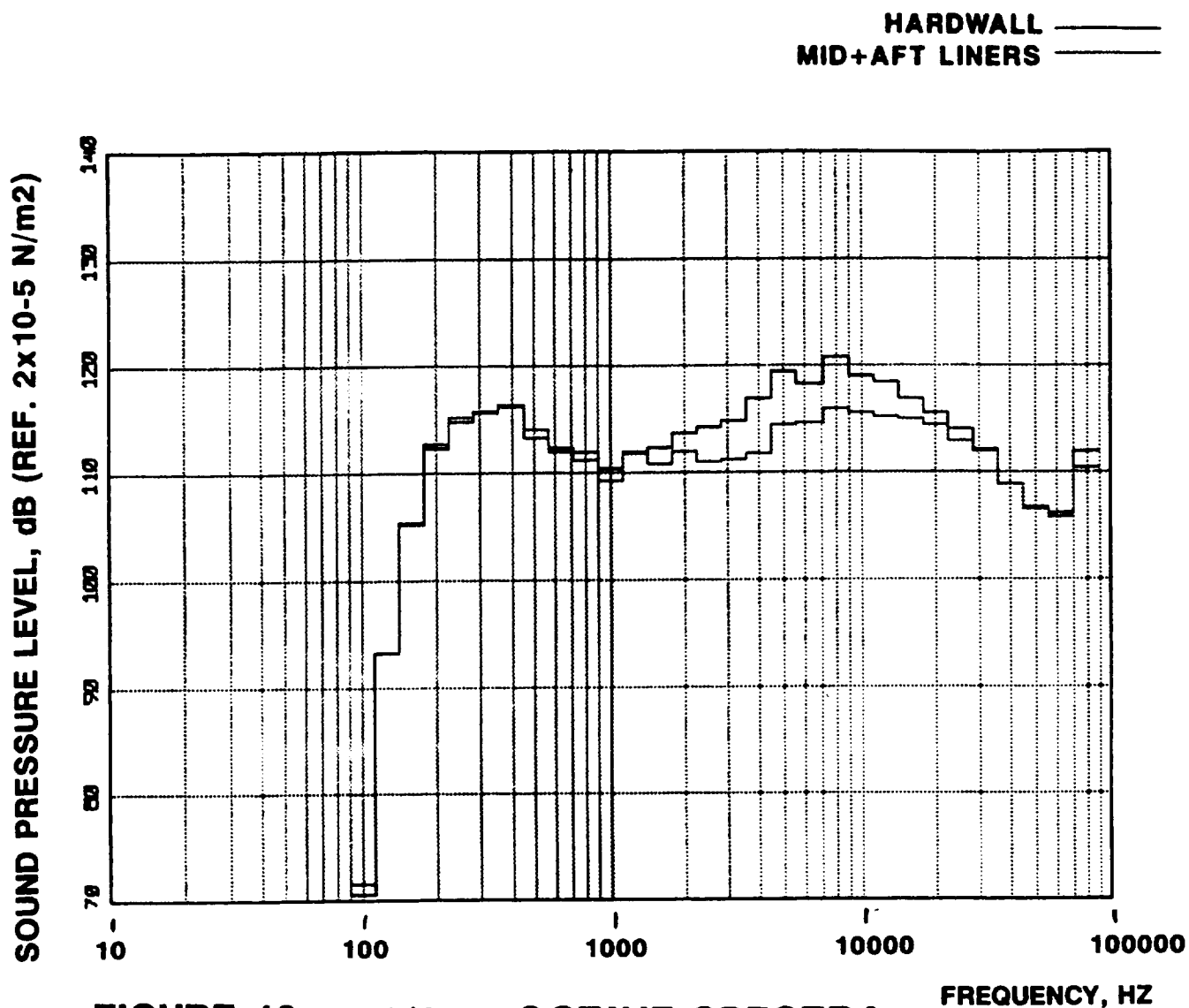
FIGURE 19   1/3   OCTAVE SPECTRA   FREQUENCY, HZ

50 DEGREE ANGLE AT TAKEOFF

HARDWALL AND MID+AFT LINERS
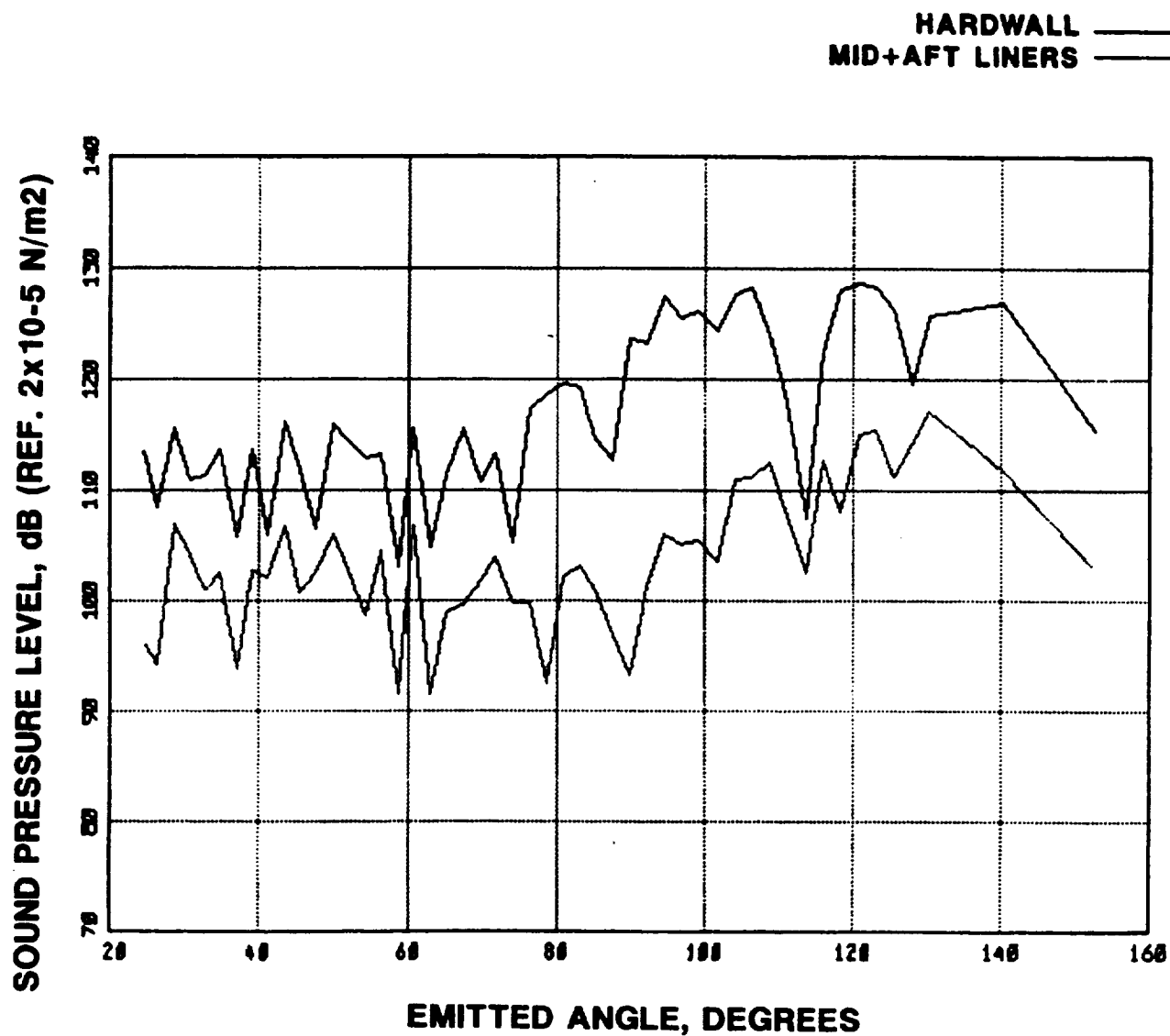
FIGURE 20   2 BPF TONE DIRECTIVITY AT 9636 RPMC

HARDWALL AND MID+AFT LINERS
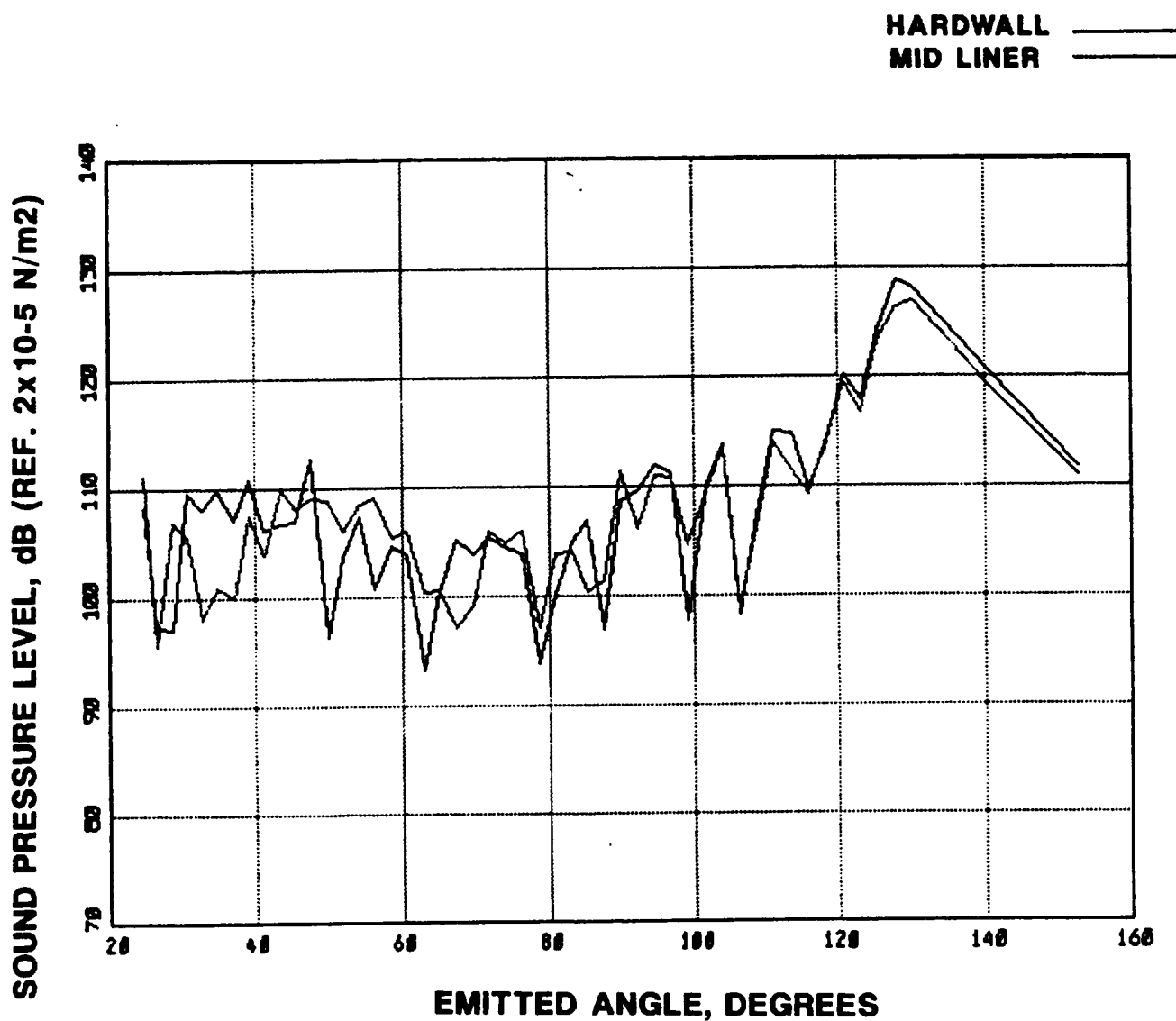
FIGURE 21   2 BPF TONE DIRECTIVITY AT CUTBACK

A. HARDWALL AND MID LINER

51
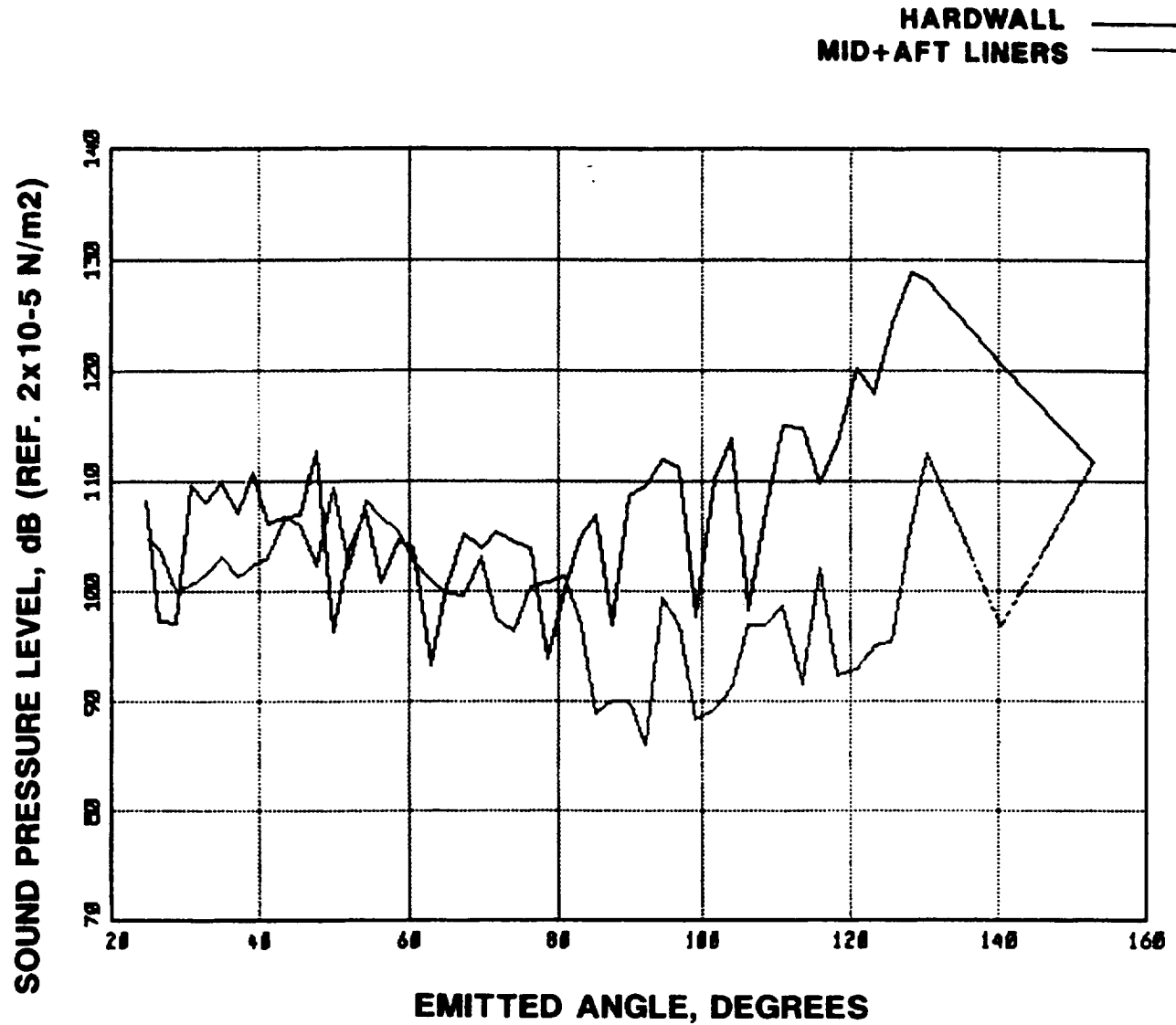
FIGURE 21   2 BPF TONE DIRECTIVITY AT CUTBACK

B.   HARDWALL AND MID+AFT LINERS
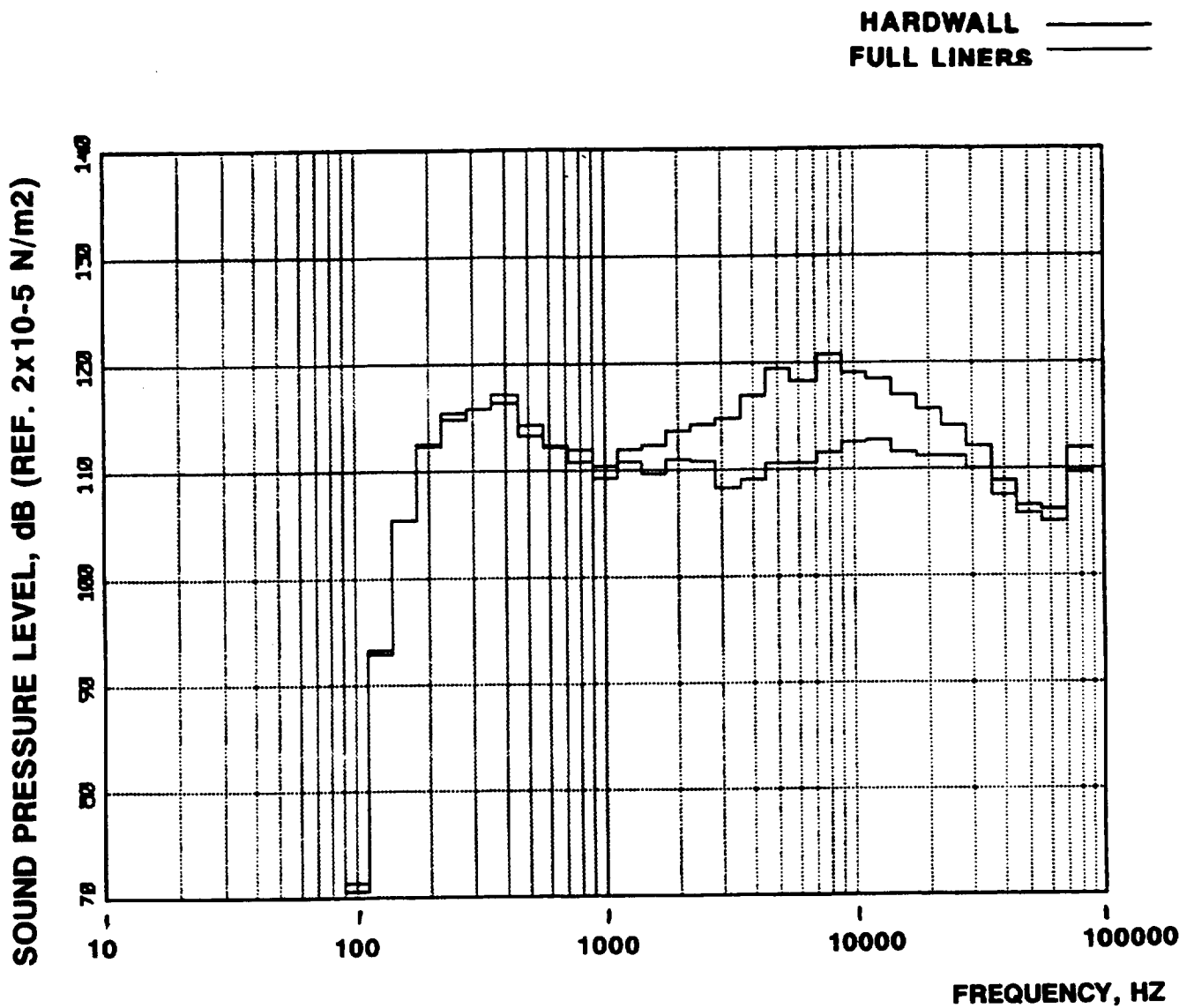
A. 1/3 OCTAVE AT 50 DEGREES

FIGURE 22 HARDWALL AND FULL LINERS
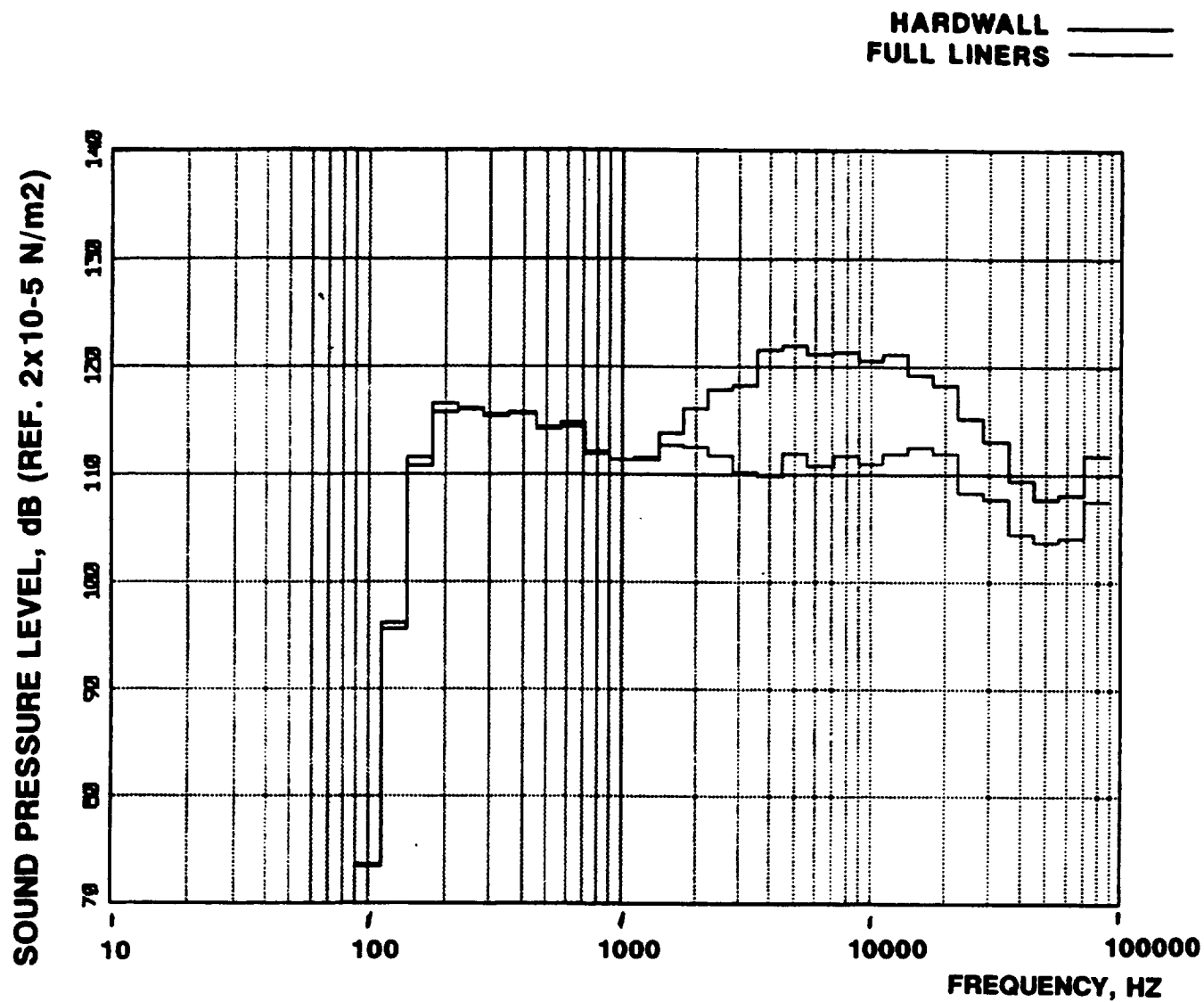
TAKEOFF

B. 1/3   OCTAVE AT 90 DEGREES

FIGURE 22   HARDWALL AND FULL LINERS

TAKEOFF

C. 1/3   OCTAVE AT 130 DEGREES
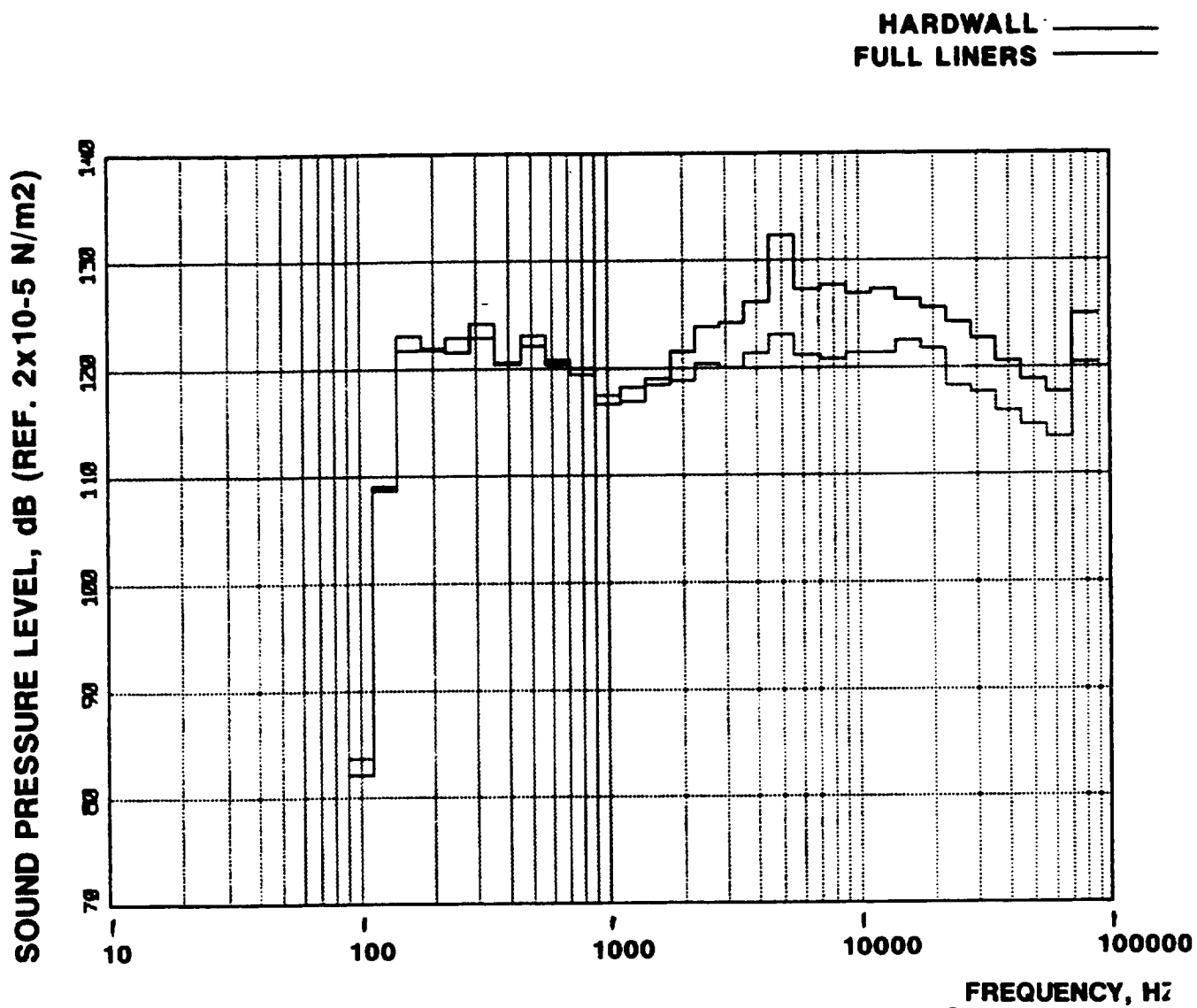
FIGURE 22   HARDWALL AND FULL LINERS

TAKEOFF

FIGURE 23   ATTENUATION

HARDWALL - FULL LINERS

A.   TAKEOFF AT 50 DEGREES

FIGURE 23   ATTENUATION

HARDWALL - FULL LINERS

B. TAKEOFF AT 90 DEGREES
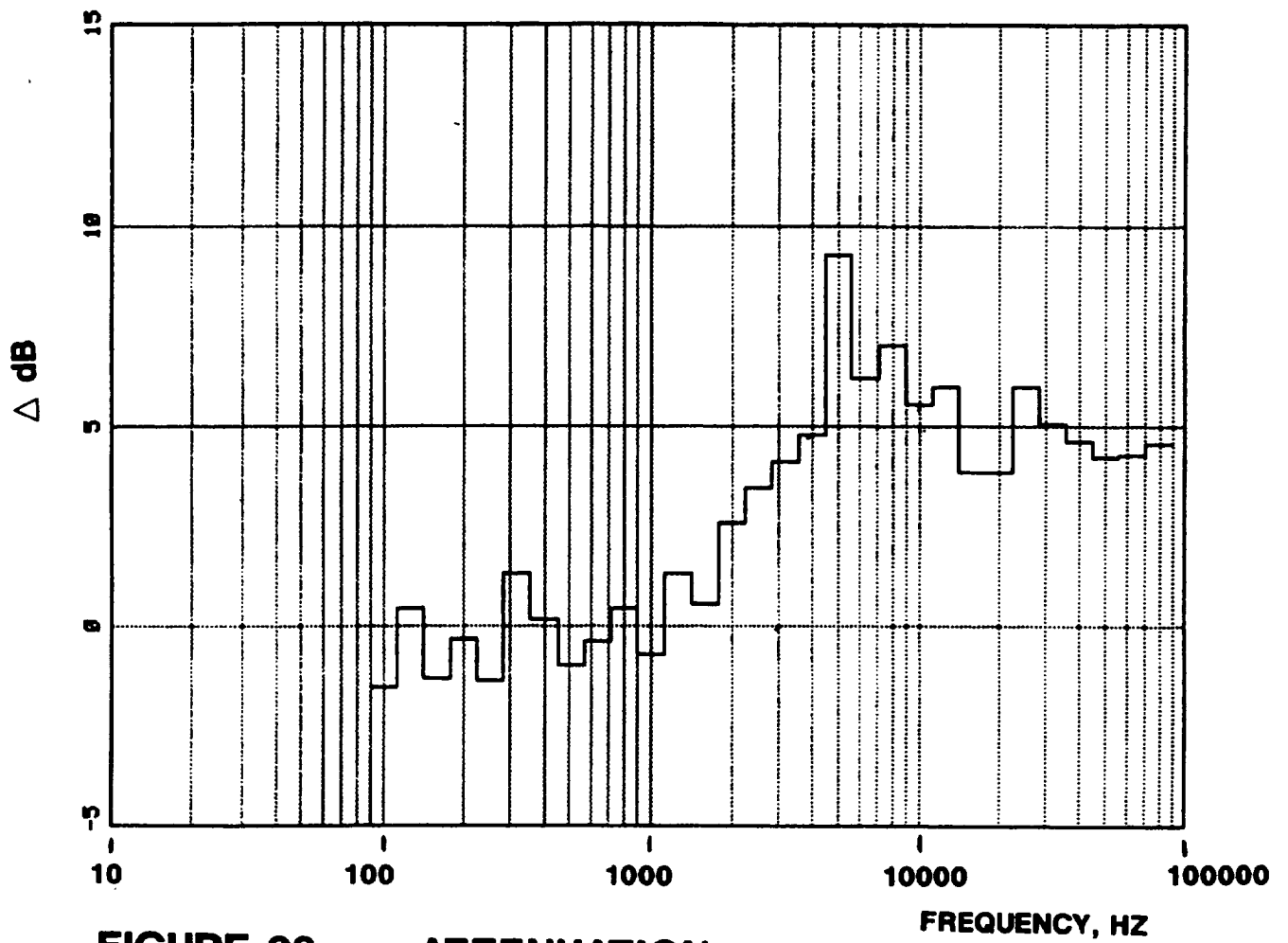
FIGURE 23   ATTENUATION

HARDWALL - FULL LINERS

C. TAKEOFF AT 130 DEGREES

58
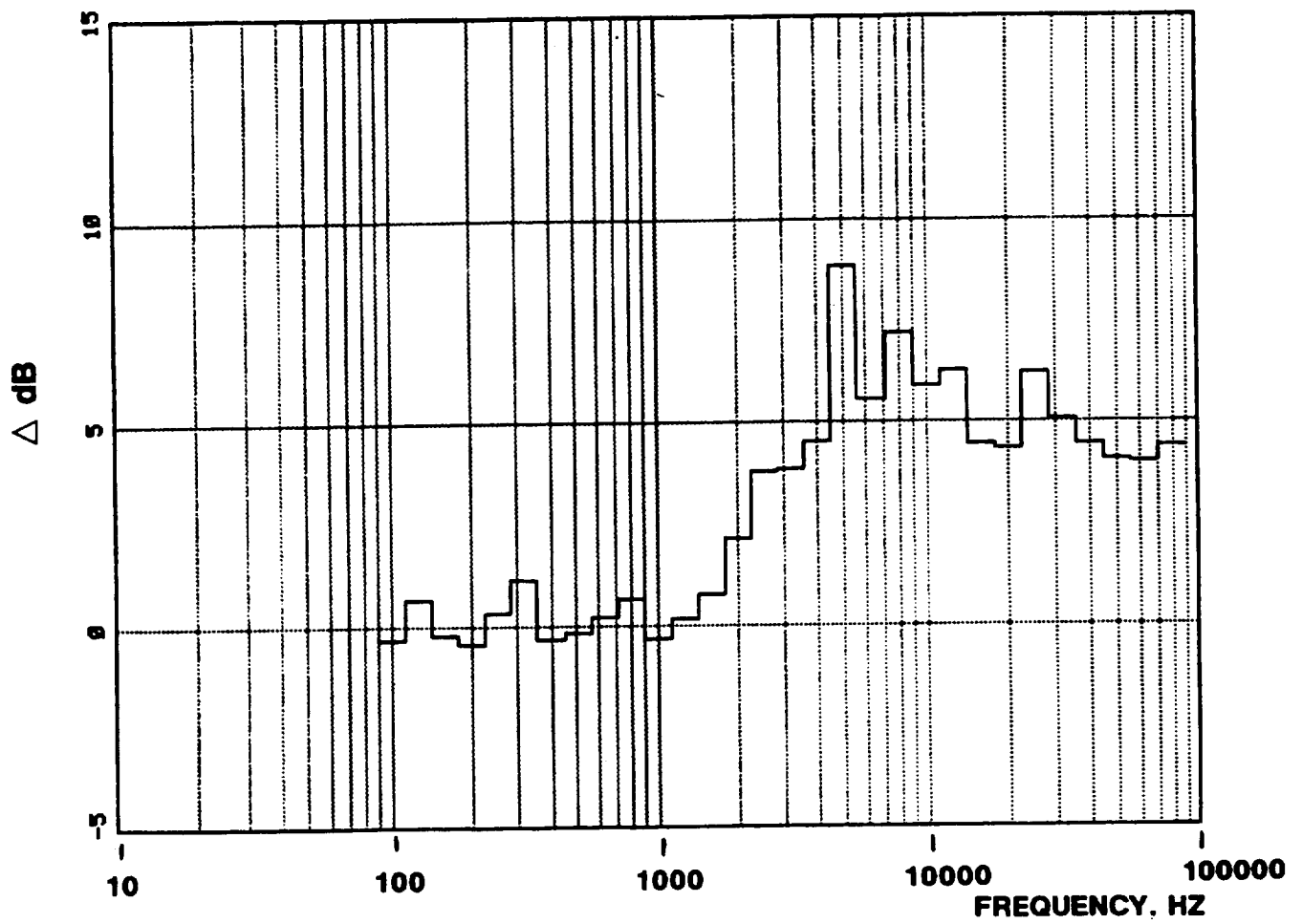
FIGURE 24   ATTENUATION

HARDWALL - MID+AFT LINERS

TAKEOFF AT 130 DEGREES
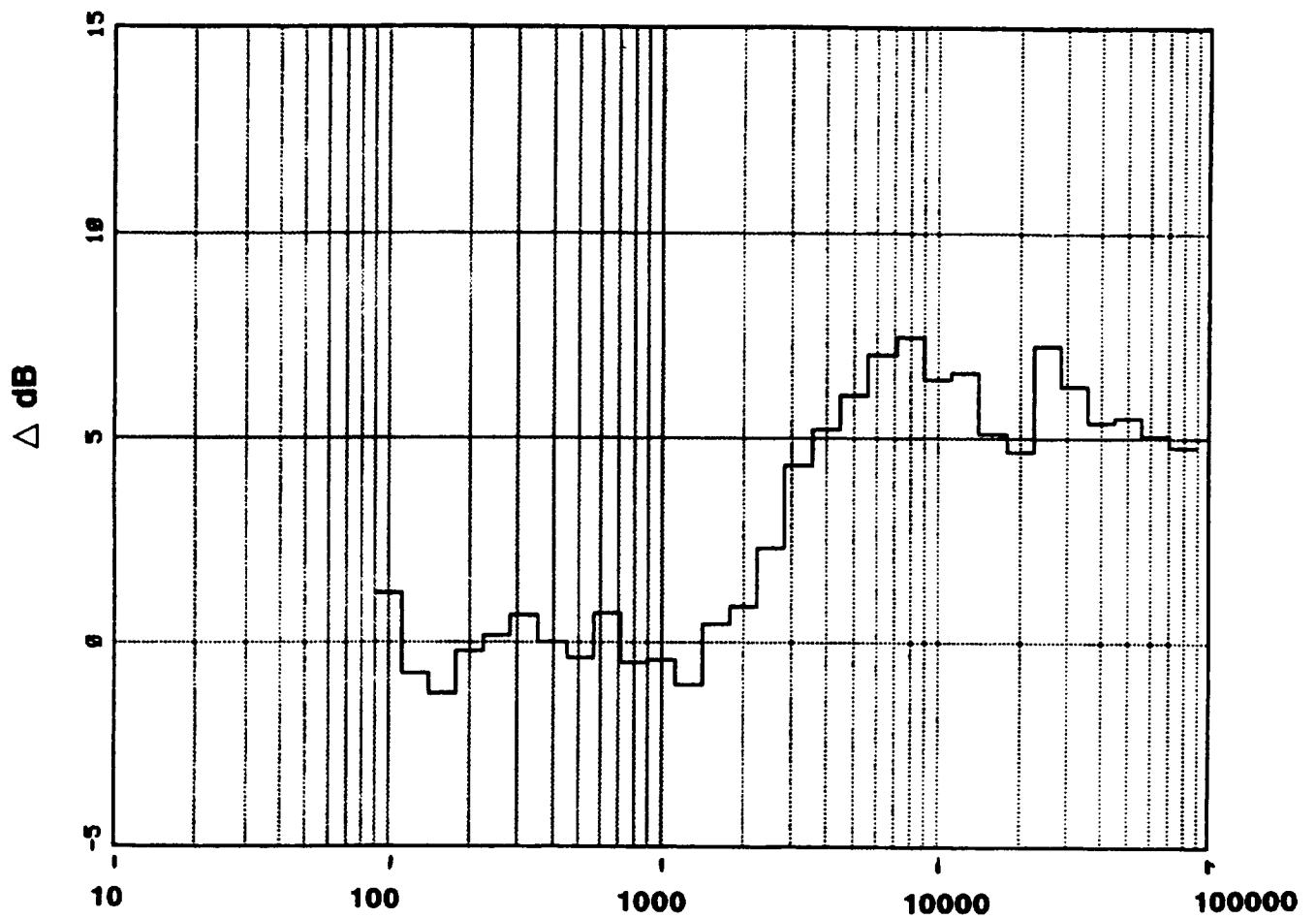
FIGURE 25   **ATTENUATION**

HARDWALL - FULL LINERS

9636 RPMC AT 130 DEGREES

FIGURE 26   ATTENUATION

HARDWALL - FULL LINERS

A. CUTBACK AT 130 DEGREES

61
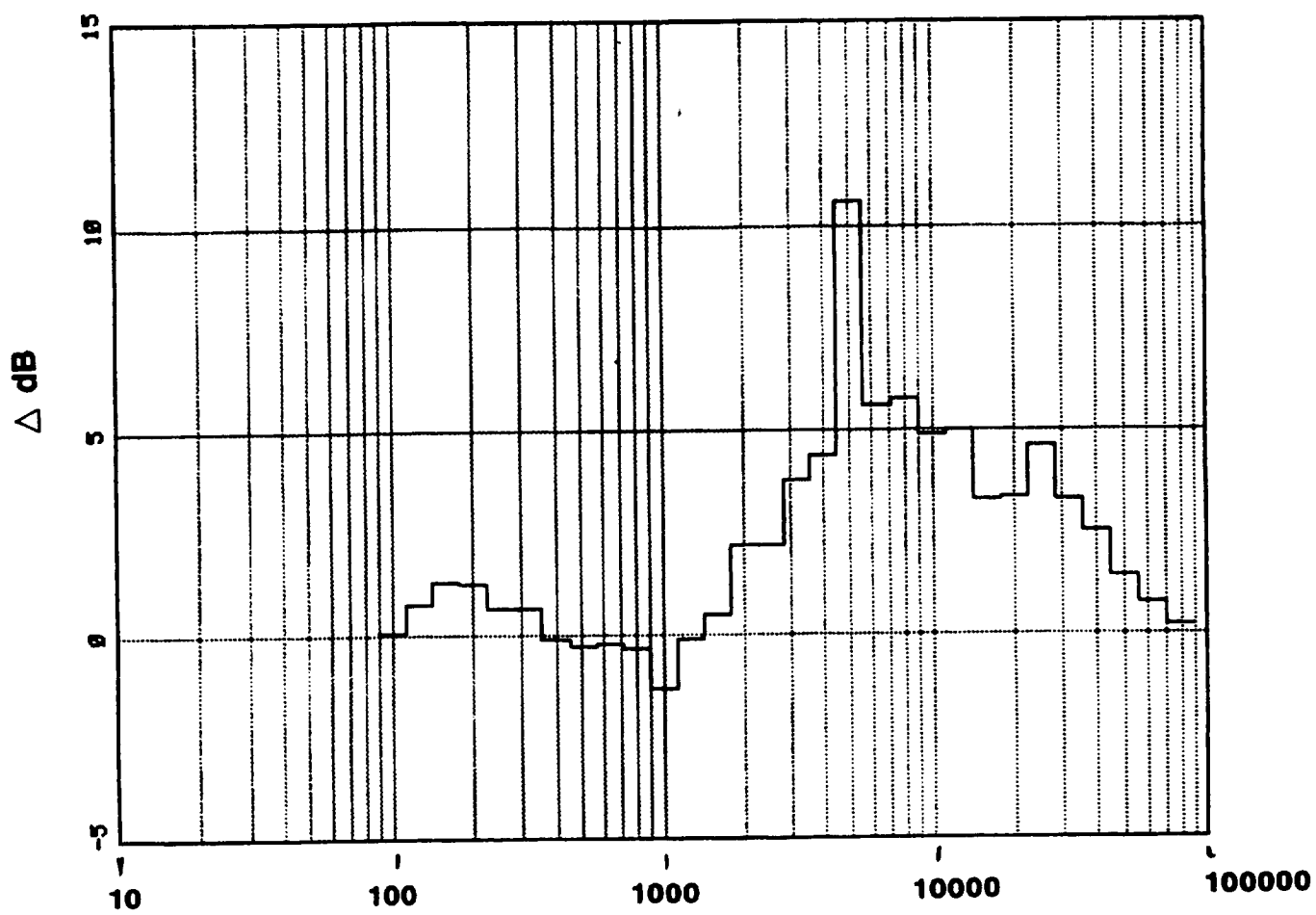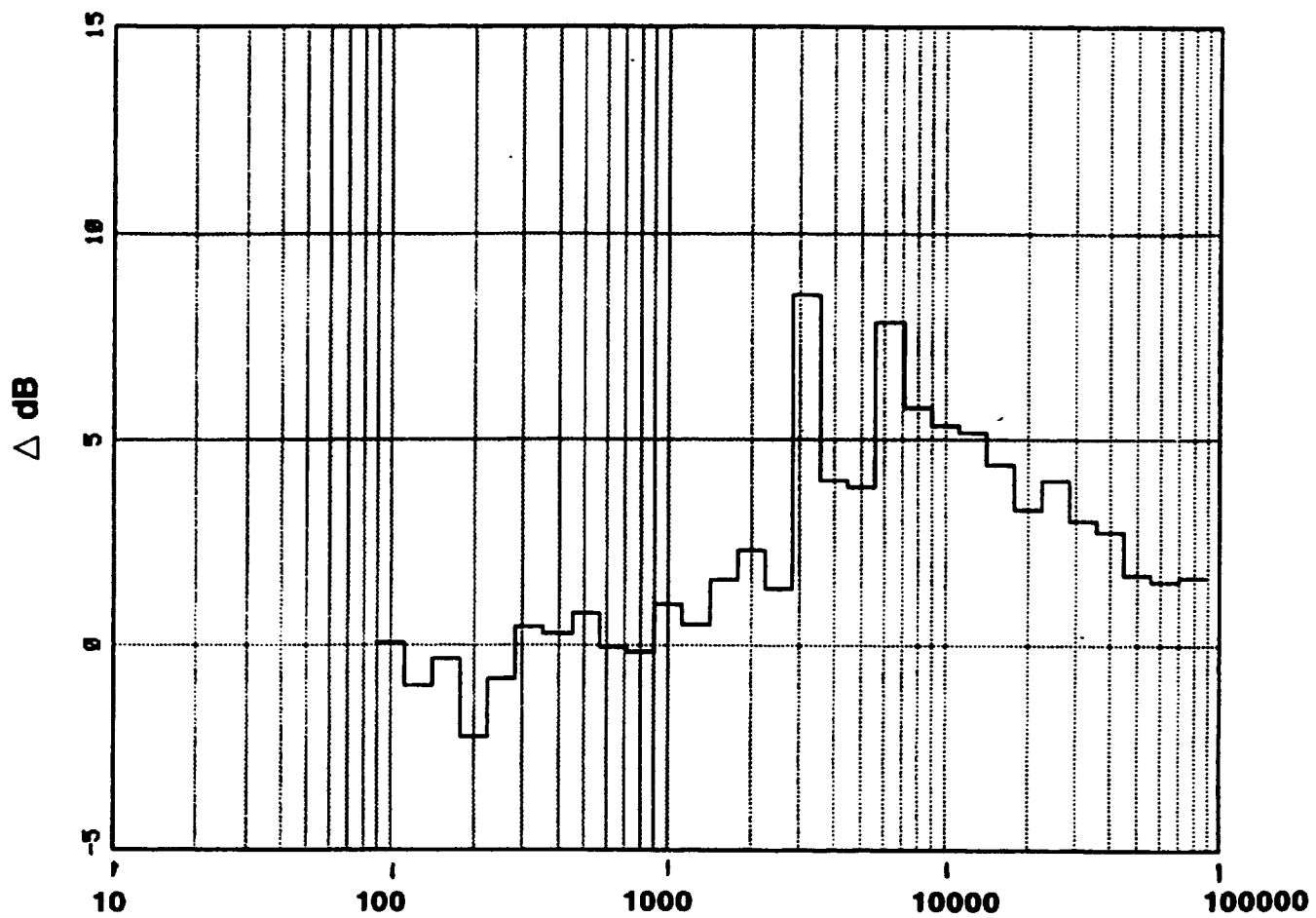
FIGURE 26 **ATTENUATION** FREQUENCY, HZ

HARDWALL - FULL LINERS

B. APPROACH AT 130 DEGREES
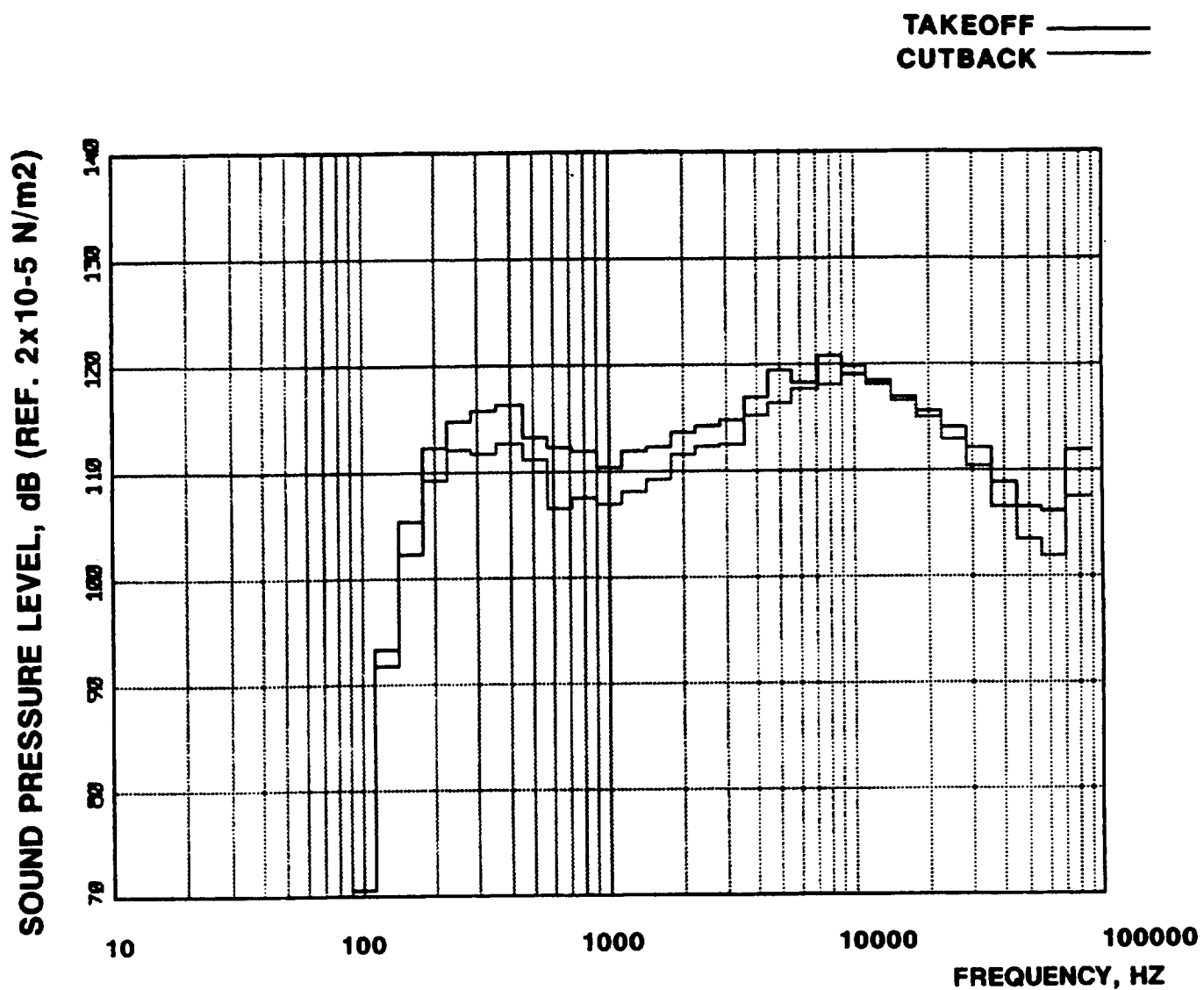
FIGURE 27   1/3   OCTAVE SPECTRA

HARDWALL AT TAKEOFF AND CUTBACK

A. 50 DEGREES
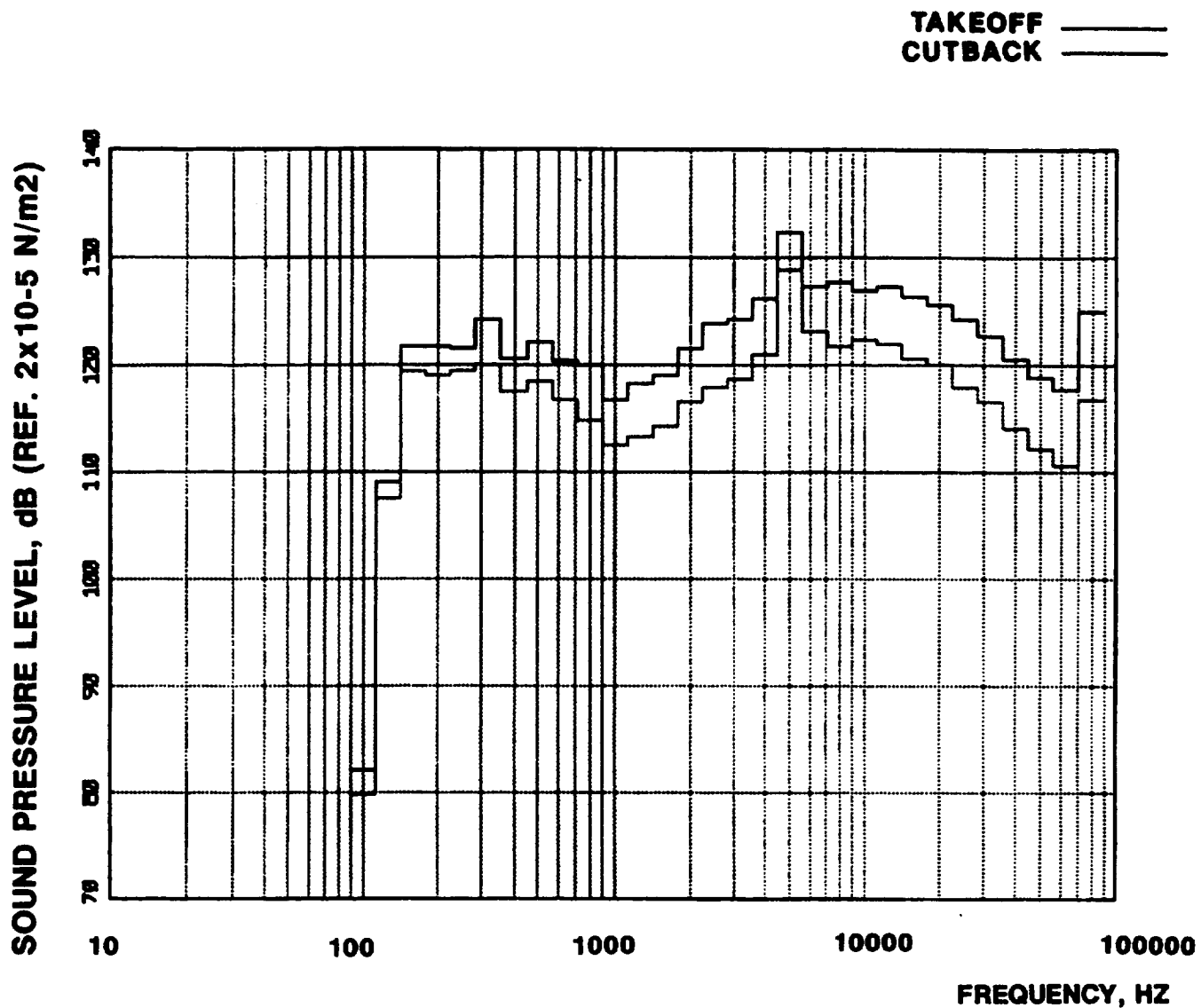
FIGURE 27   1/3   OCTAVE SPECTRA

HARDWALL AT TAKEOFF AND CUTBACK

B.   130DEGREES
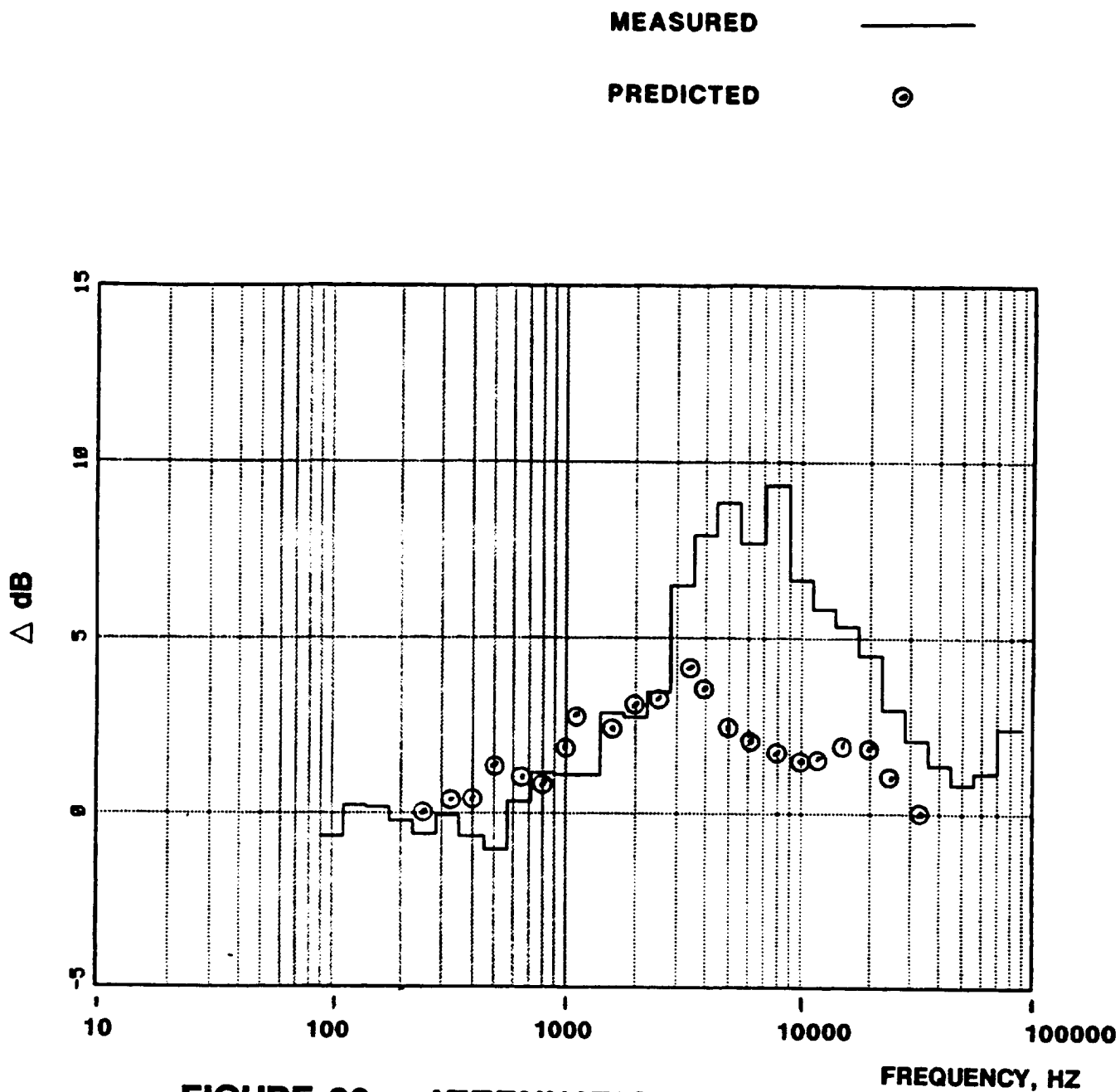
64

FIGURE 28   ATTENUATION

HARDWALL - FULL LINERS

A. TAKEOFF AT 50 DEGREES

65
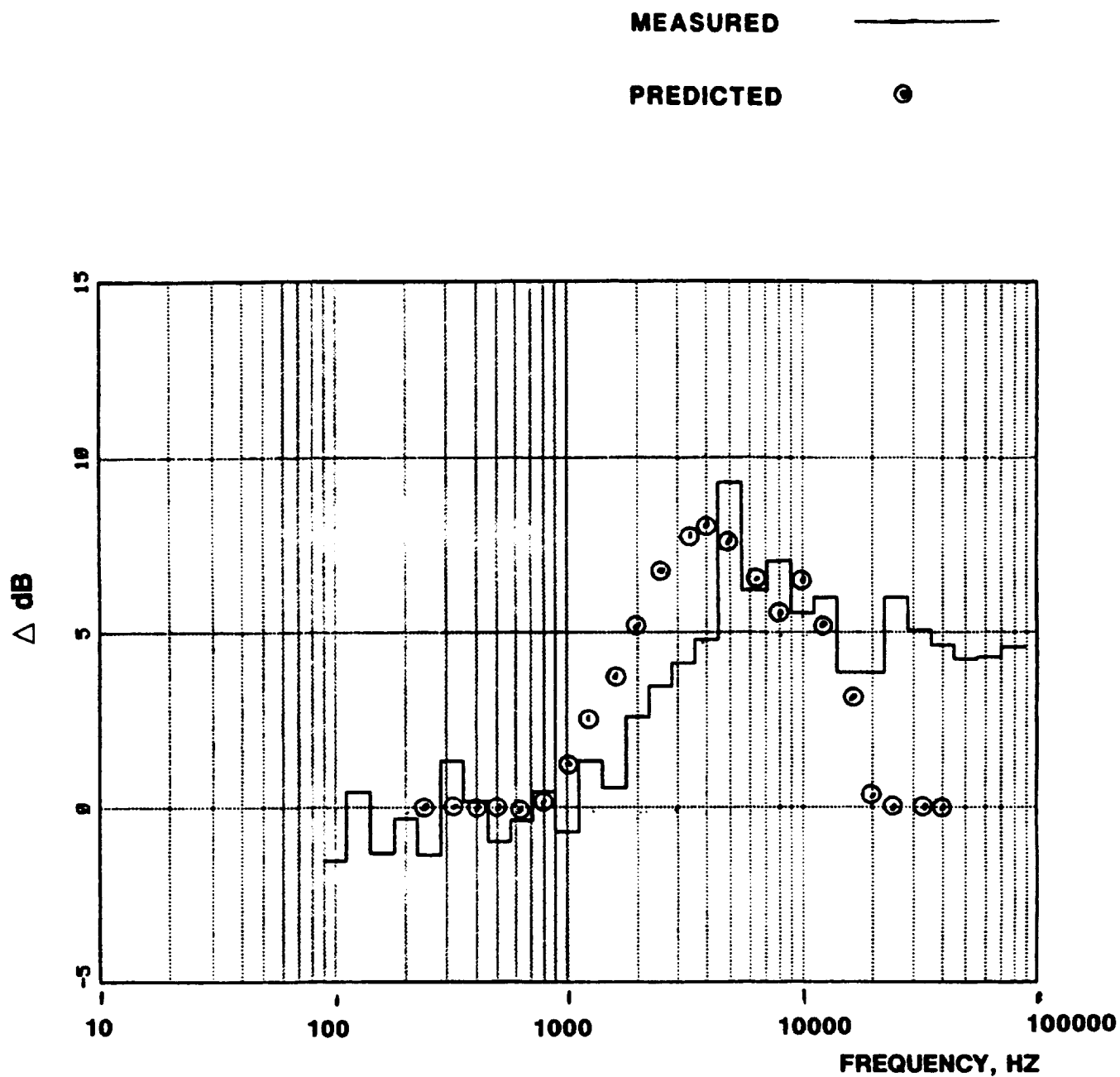
FIGURE 28 ATTENUATION

HARDWALL - FULL LINERS

B. TAKEOFF AT 130 DEGREES

66
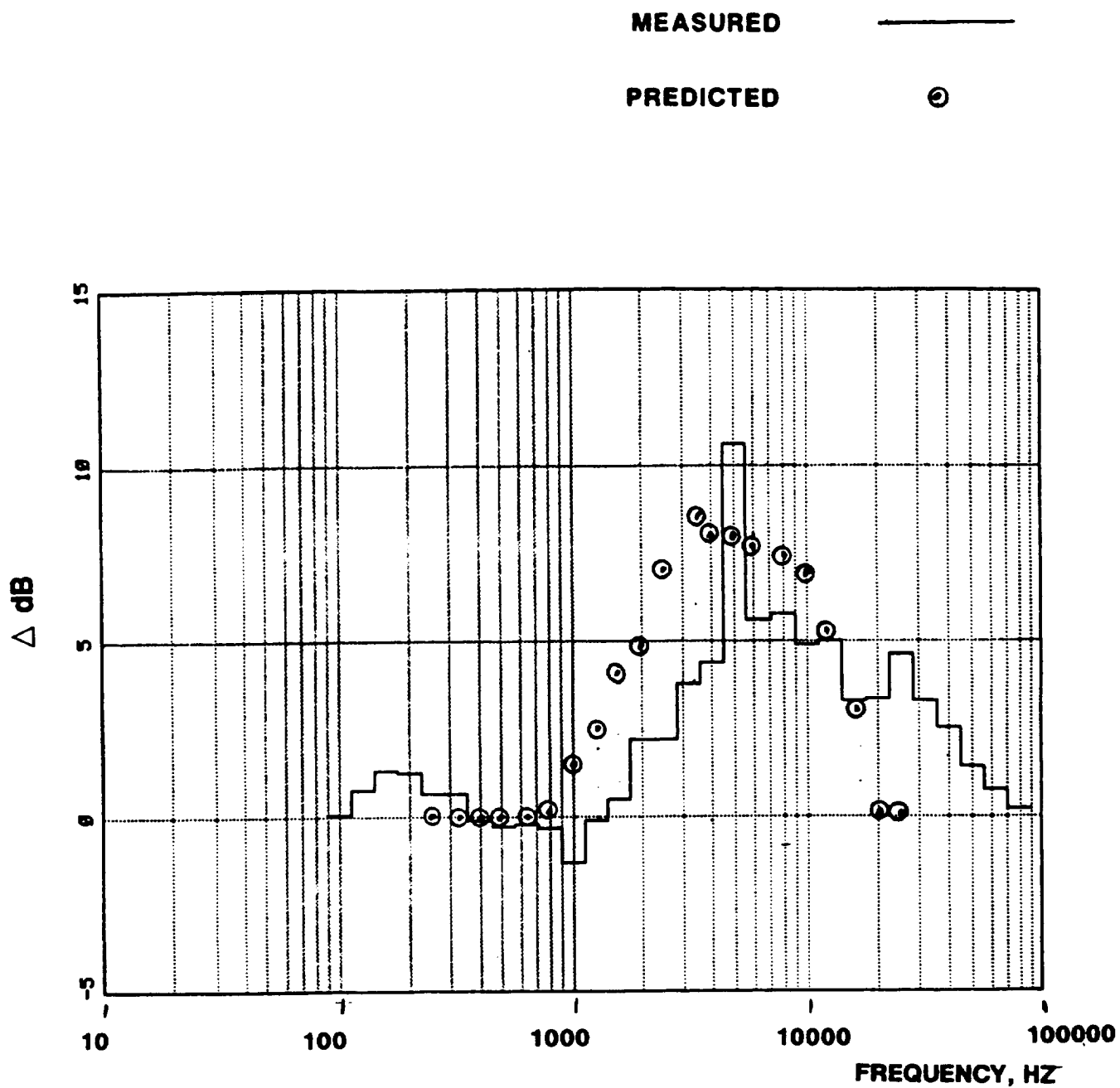
FIGURE 29   ATTENUATION

HARDWALL - FULL LINERS

CUTBACK AT 130 DEGREES
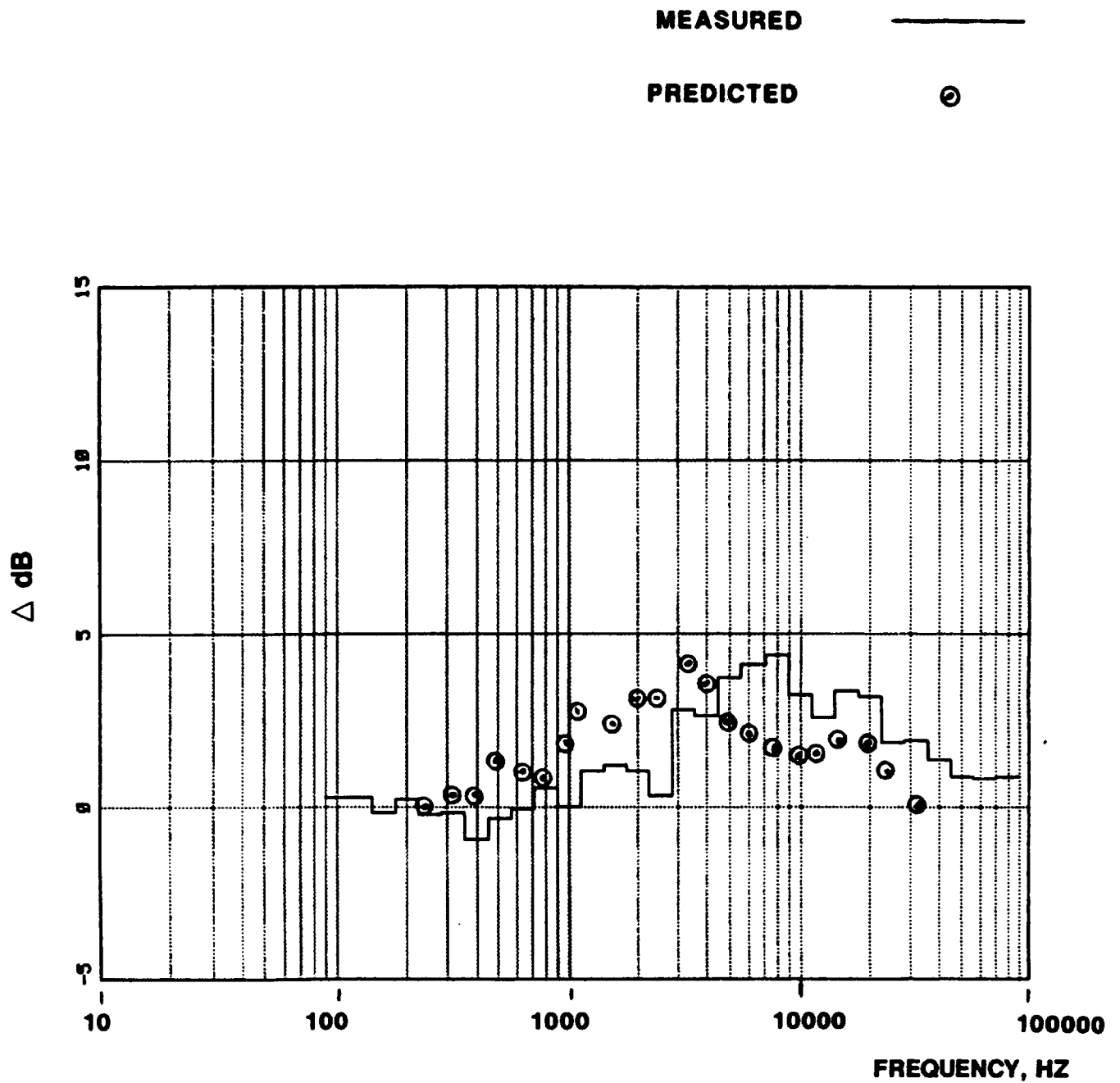
FIGURE 30   ATTENUATION

MID+AFT LINERS - FULL LINERS

TAKEOFF AT 50 DEGREES
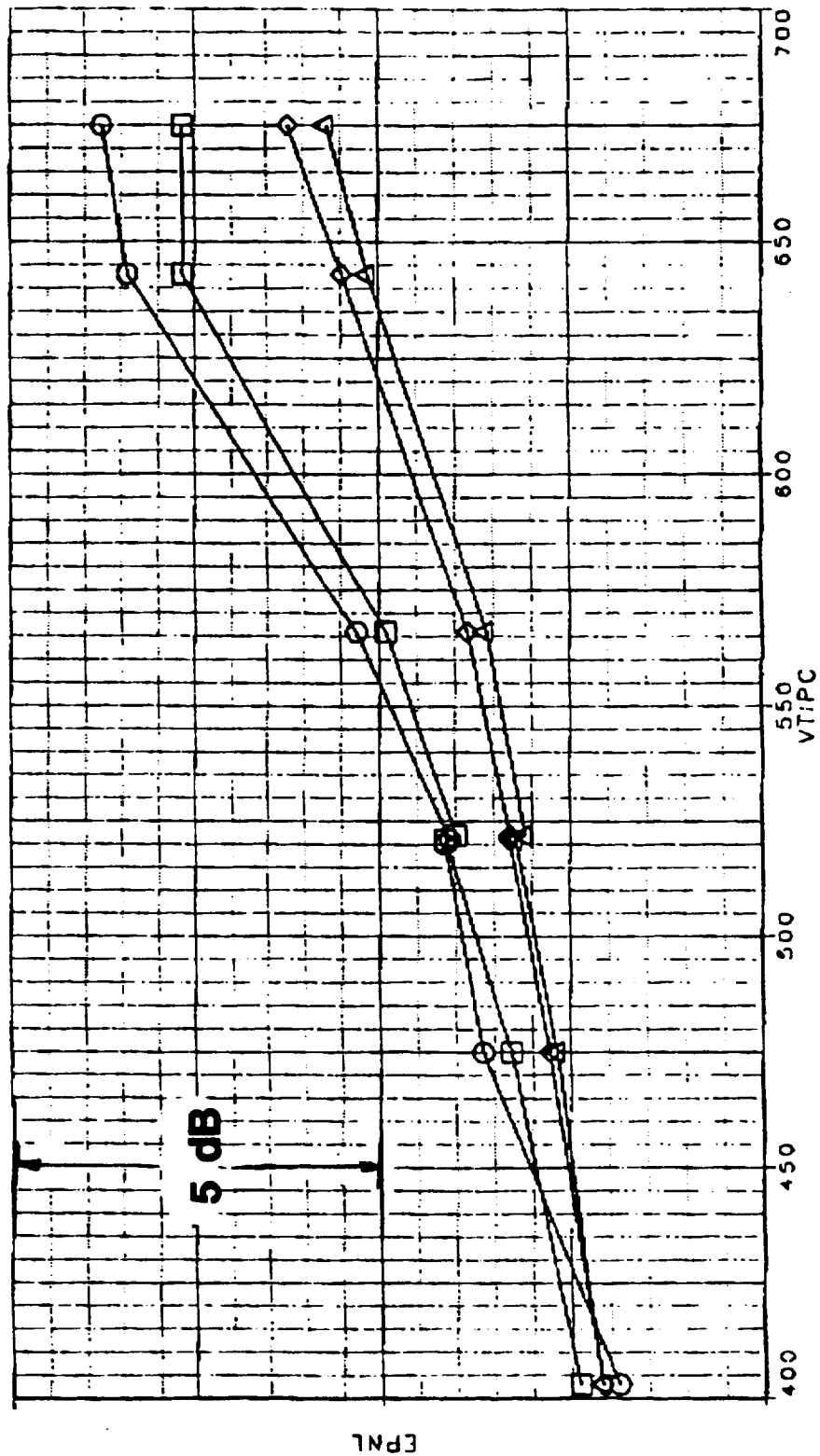
FIGURE 31 EPNL AT APPROACH
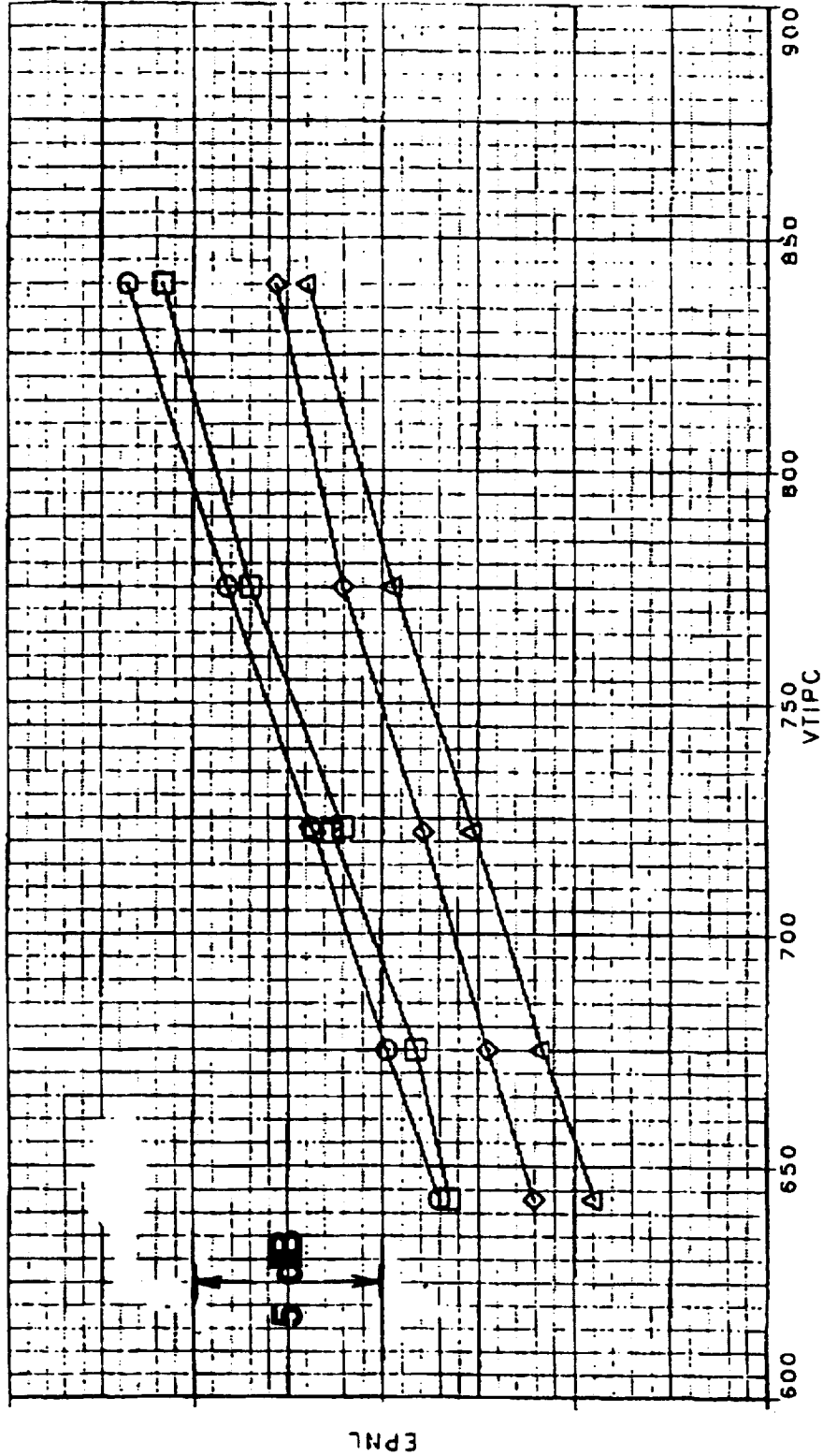
FIGURE 32 EPNL AT CUTBACK
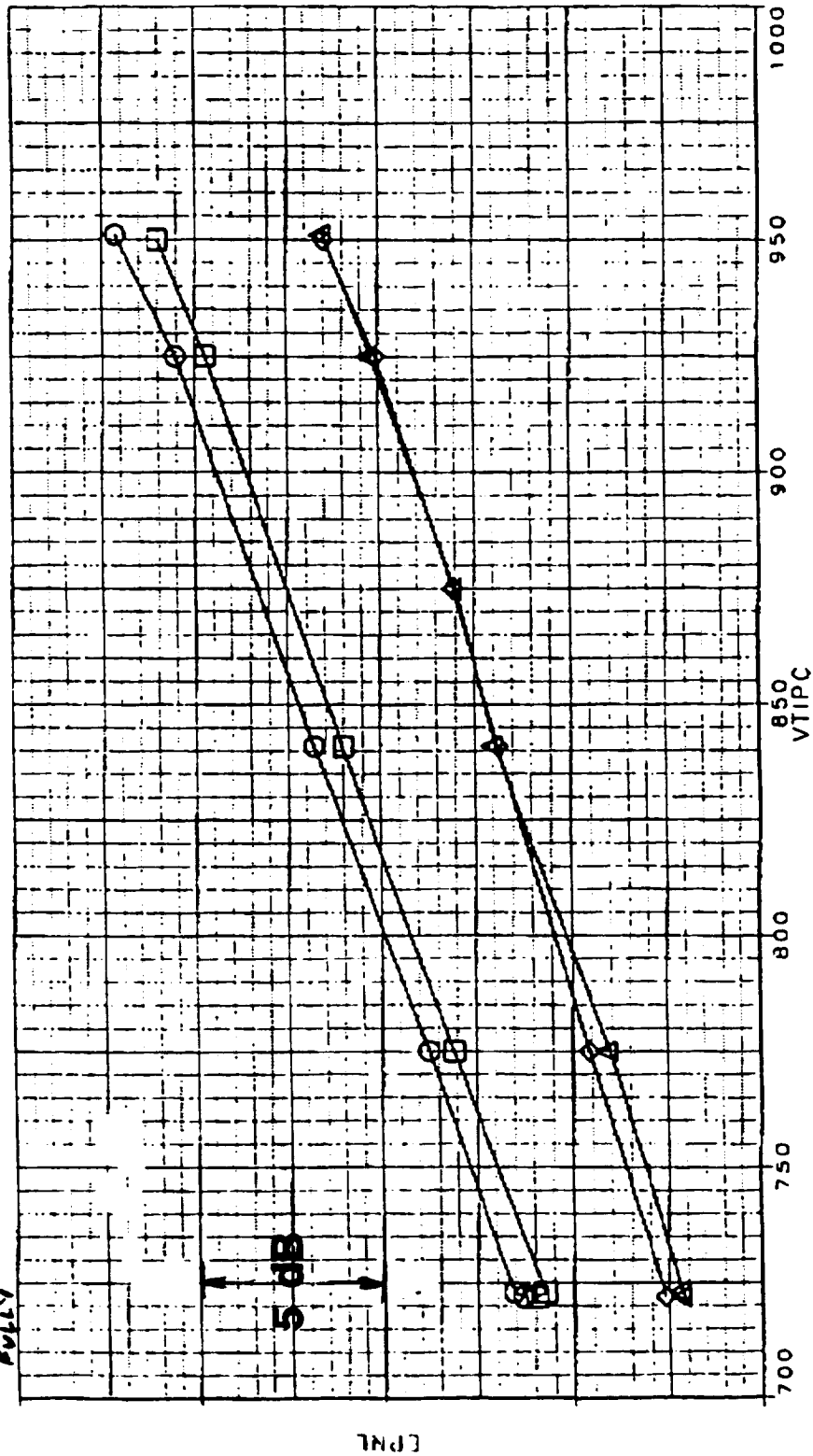
FIGURE 33 EPNL AT TAKEOFF

71
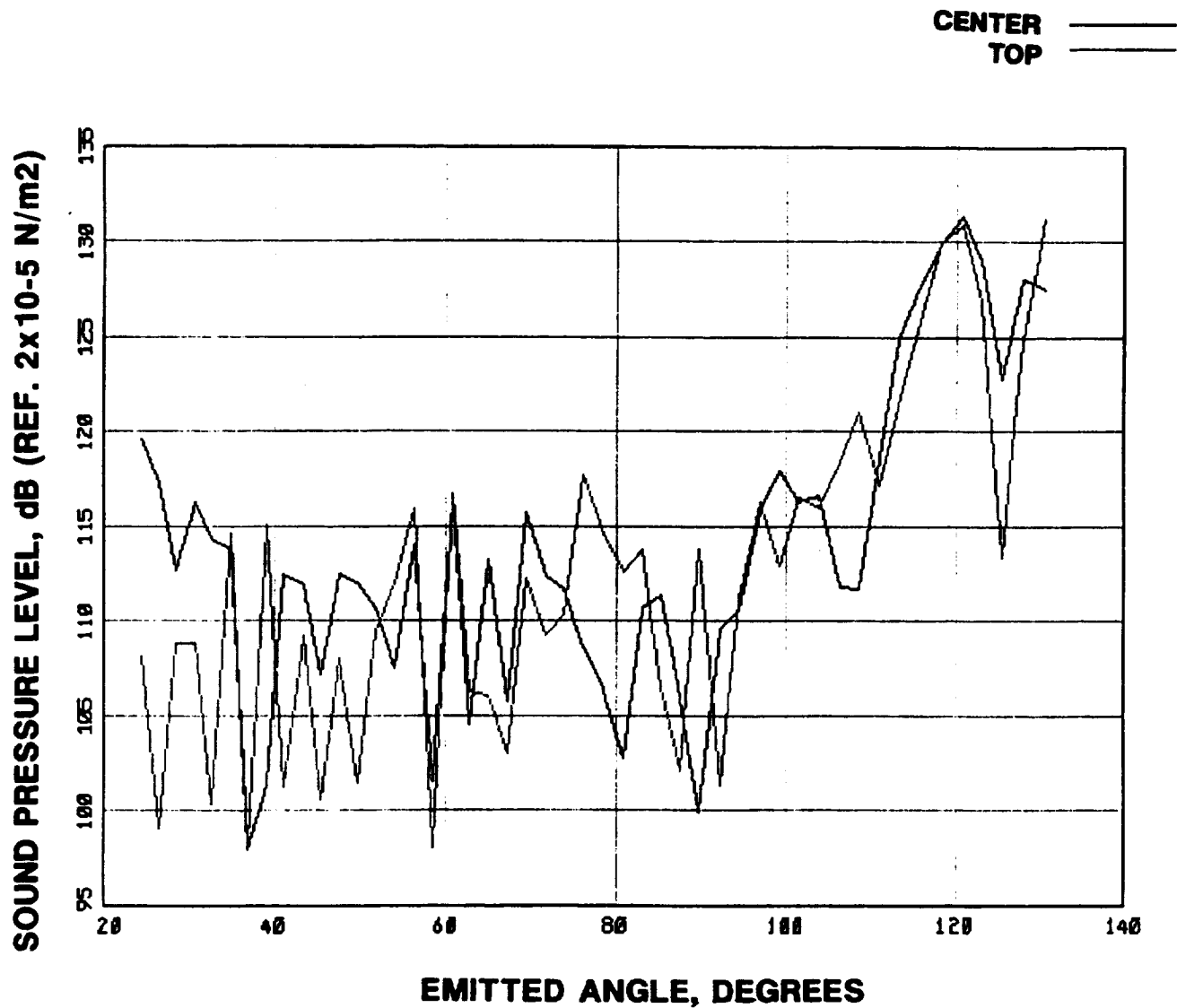
FIGURE 34 2 BPF DIRECTIVITY AT TAKEOFF

A. CENTER AND TOP MICROPHONES
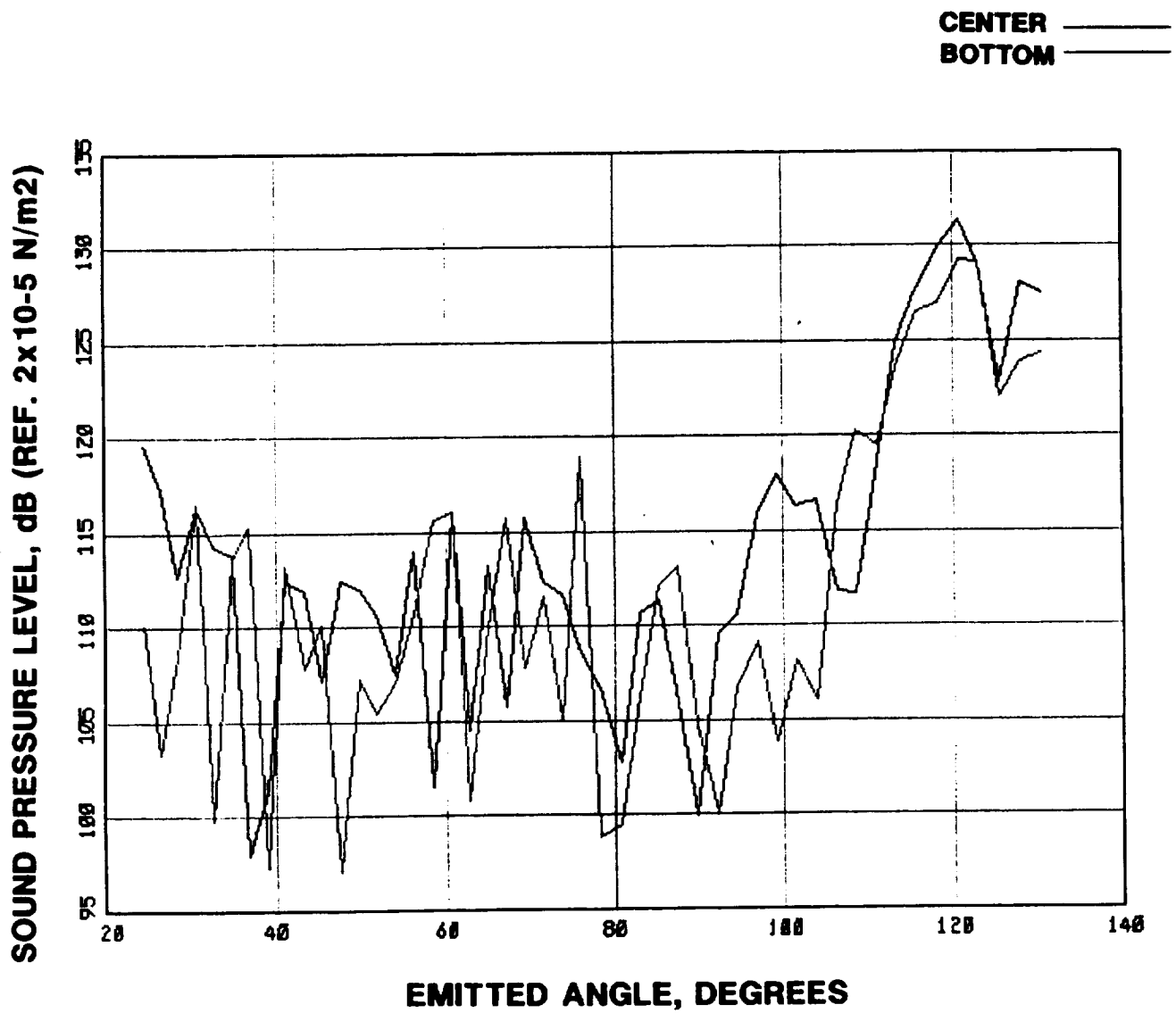
FIGURE 34 2 BPF DIRECTIVITY AT TAKEOFF

B. CENTER AND BOTTOM MICROPHONES
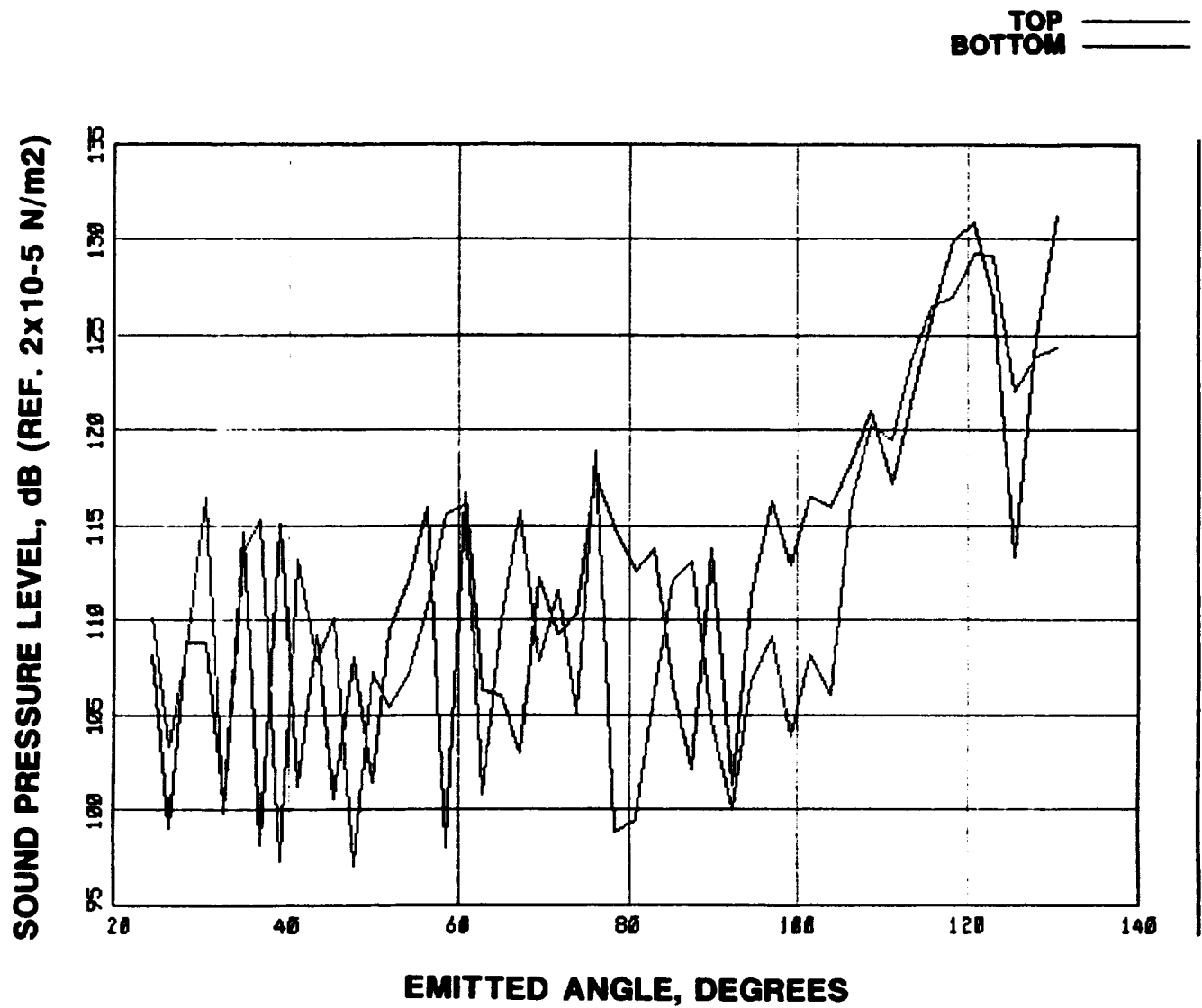
FIGURE 34 2 BPF DIRECTIVITY AT TAKEOFF

C. TOP AND BOTTOM MICROPHONES
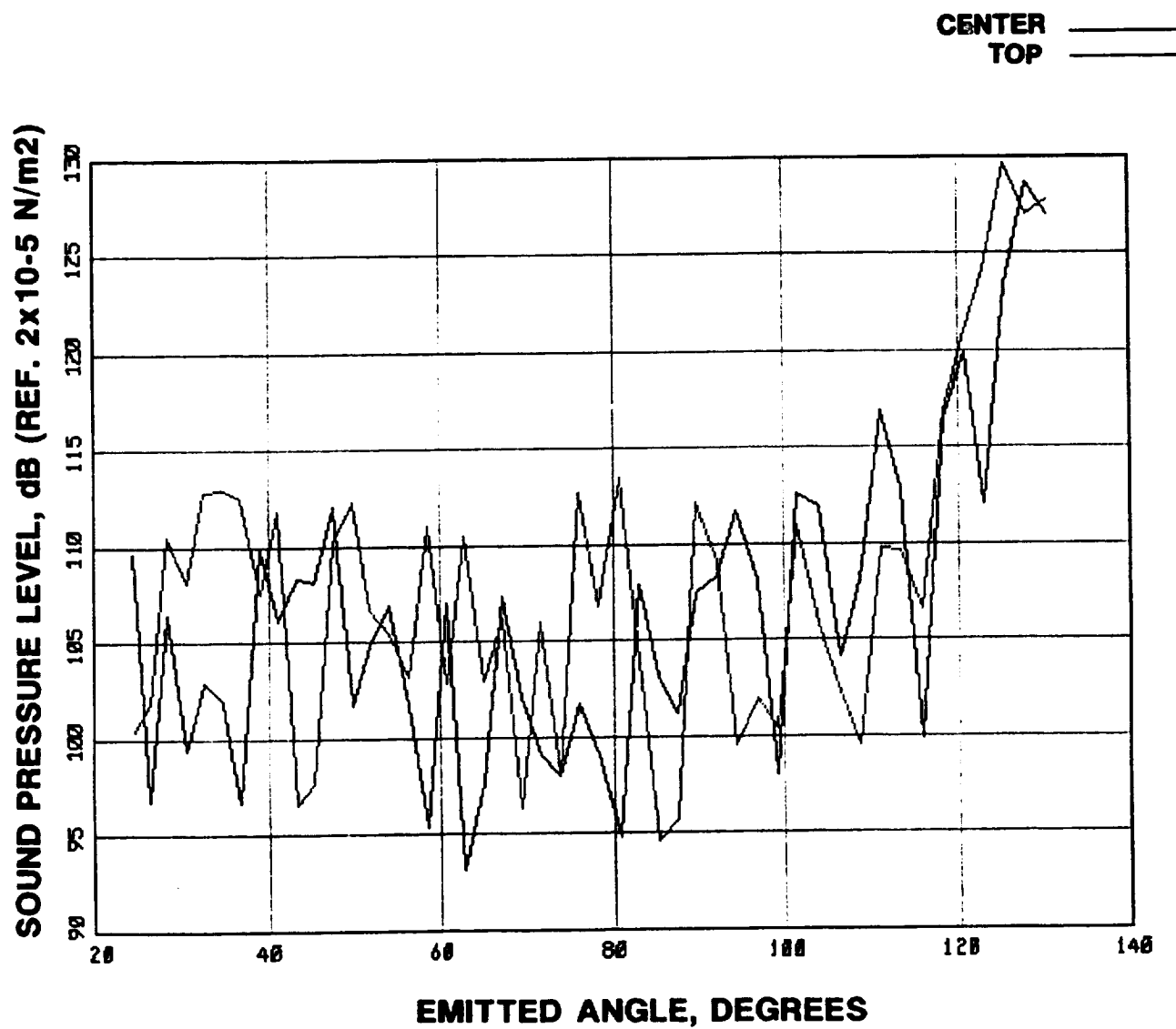
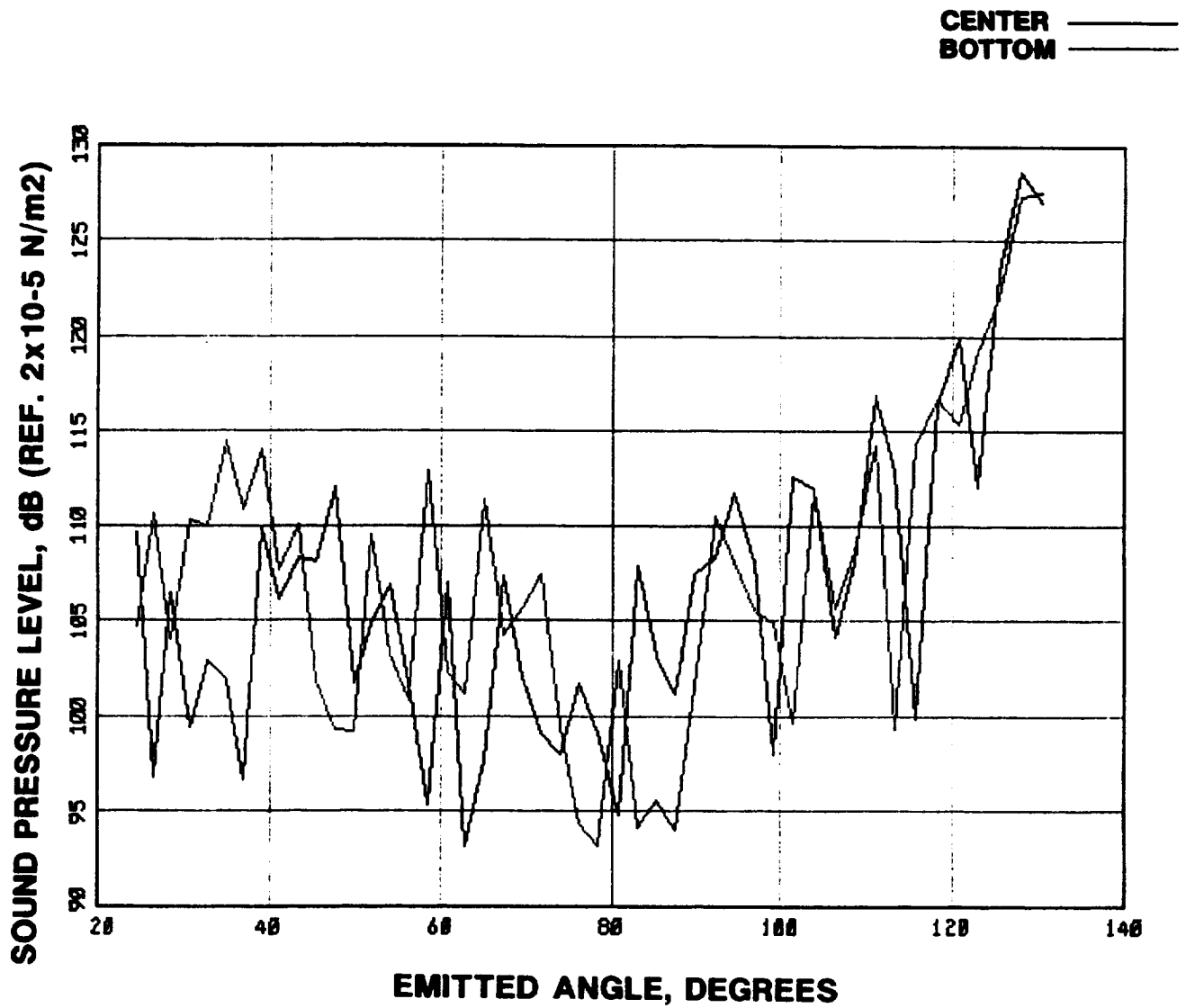**FIGURE 35   2 BPF DIRECTIVITY AT CUTBACK**

A. CENTER AND TOP MICROPHONES

FIGURE 35   2 BPF DIRECTIVITY AT CUTBACK
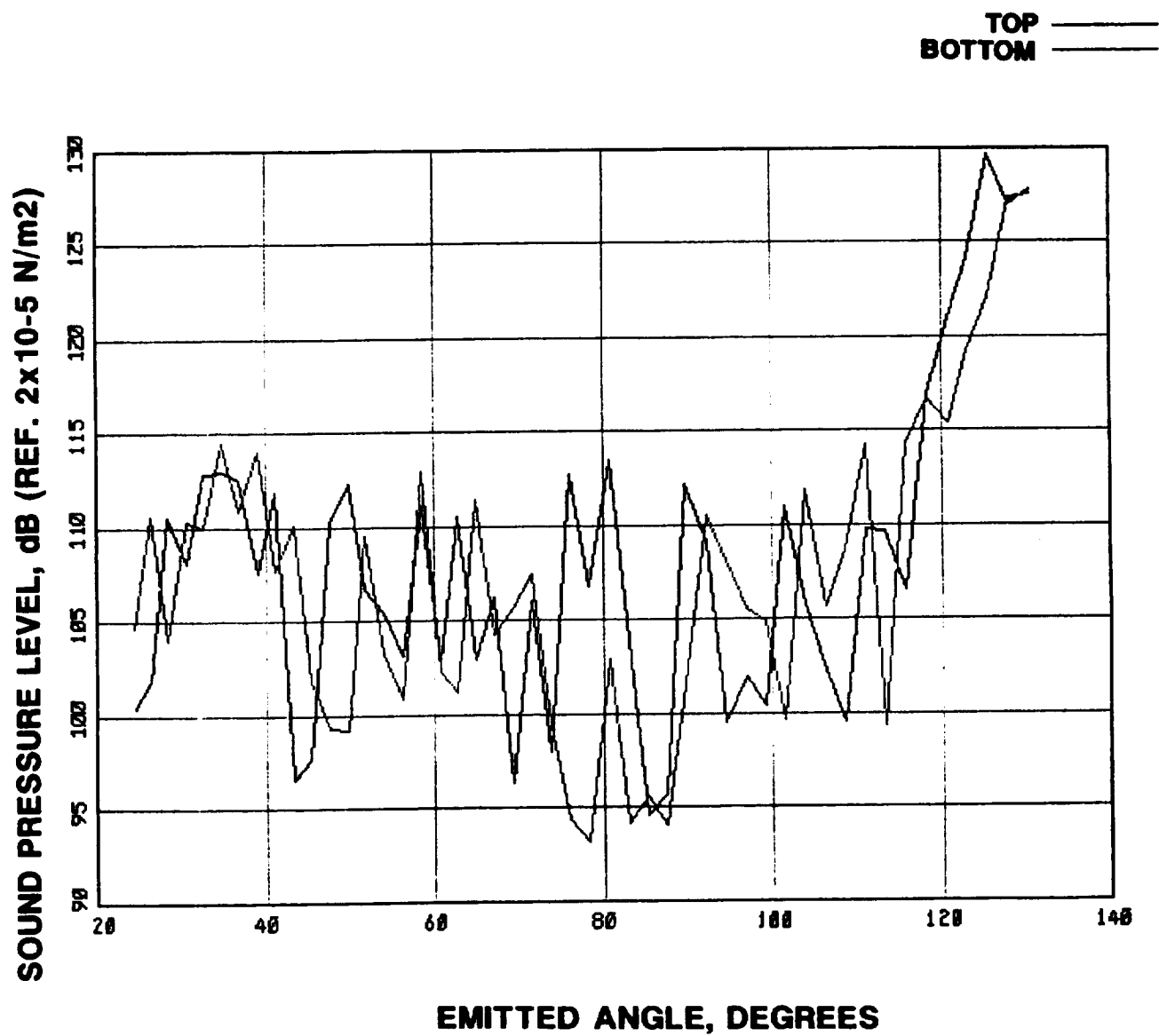

B. CENTER AND BOTTOM MICROPHONES

FIGURE 35   2 BPF DIRECTIVITY AT CUTBACK
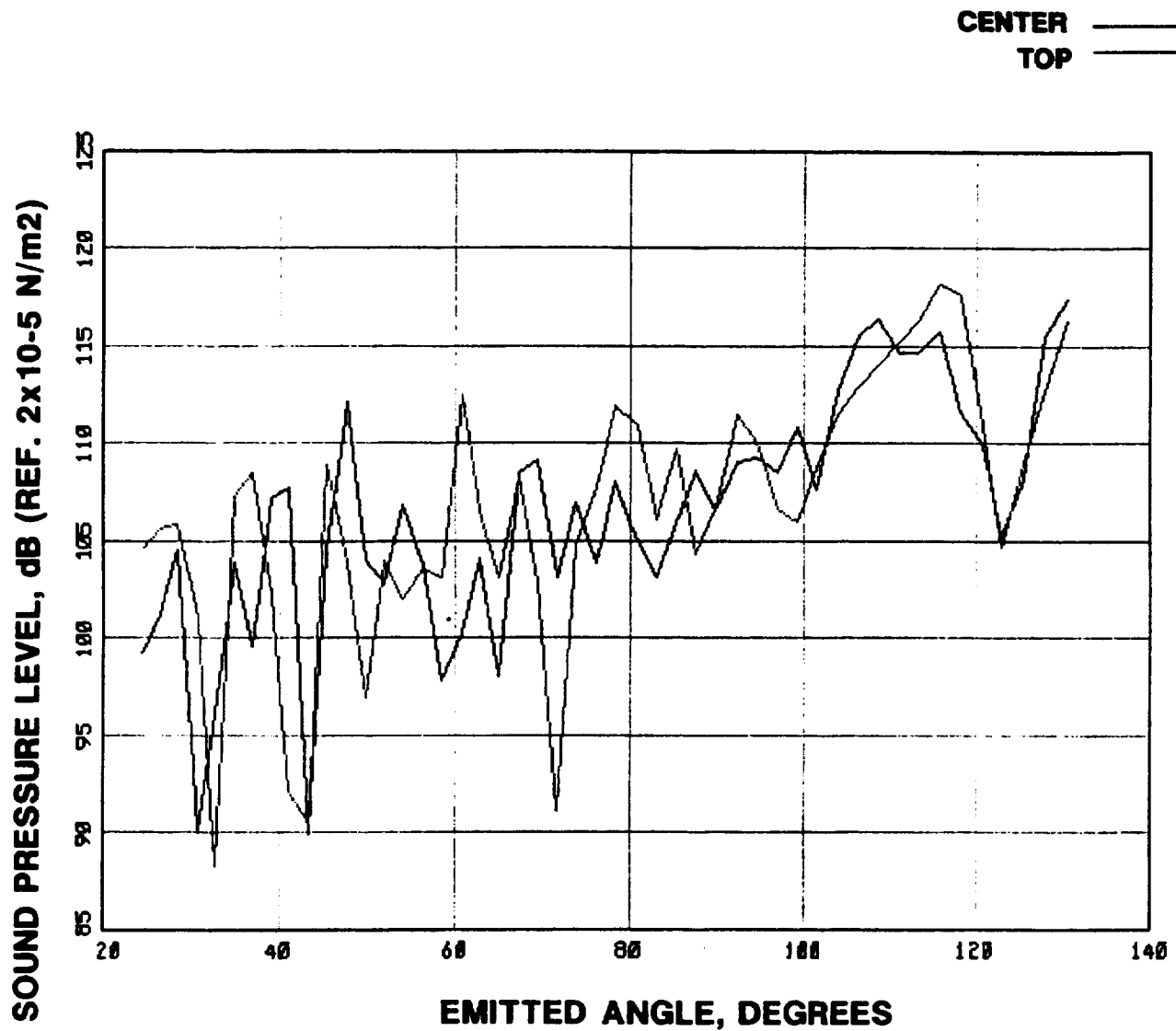
C. TOP AND BOTTOM MICROPHONES

77

EMITTED ANGLE, DEGREES

FIGURE 36   2 BPF DIRECTIVITY AT APPROACH

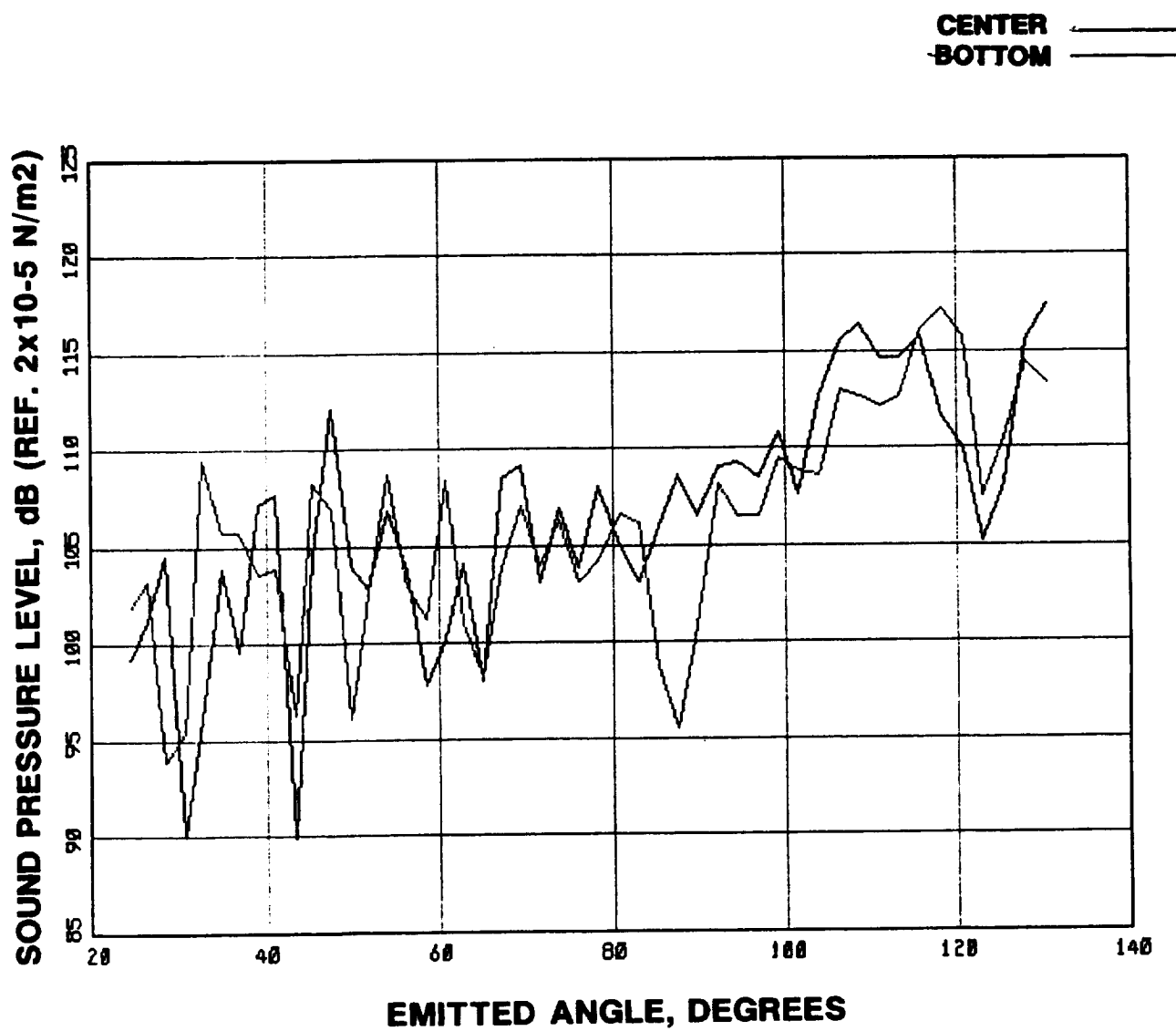**A. CENTER AND TOP MICROPHONES**

FIGURE 36   2 BPF DIRECTIVITY AT APPROACH
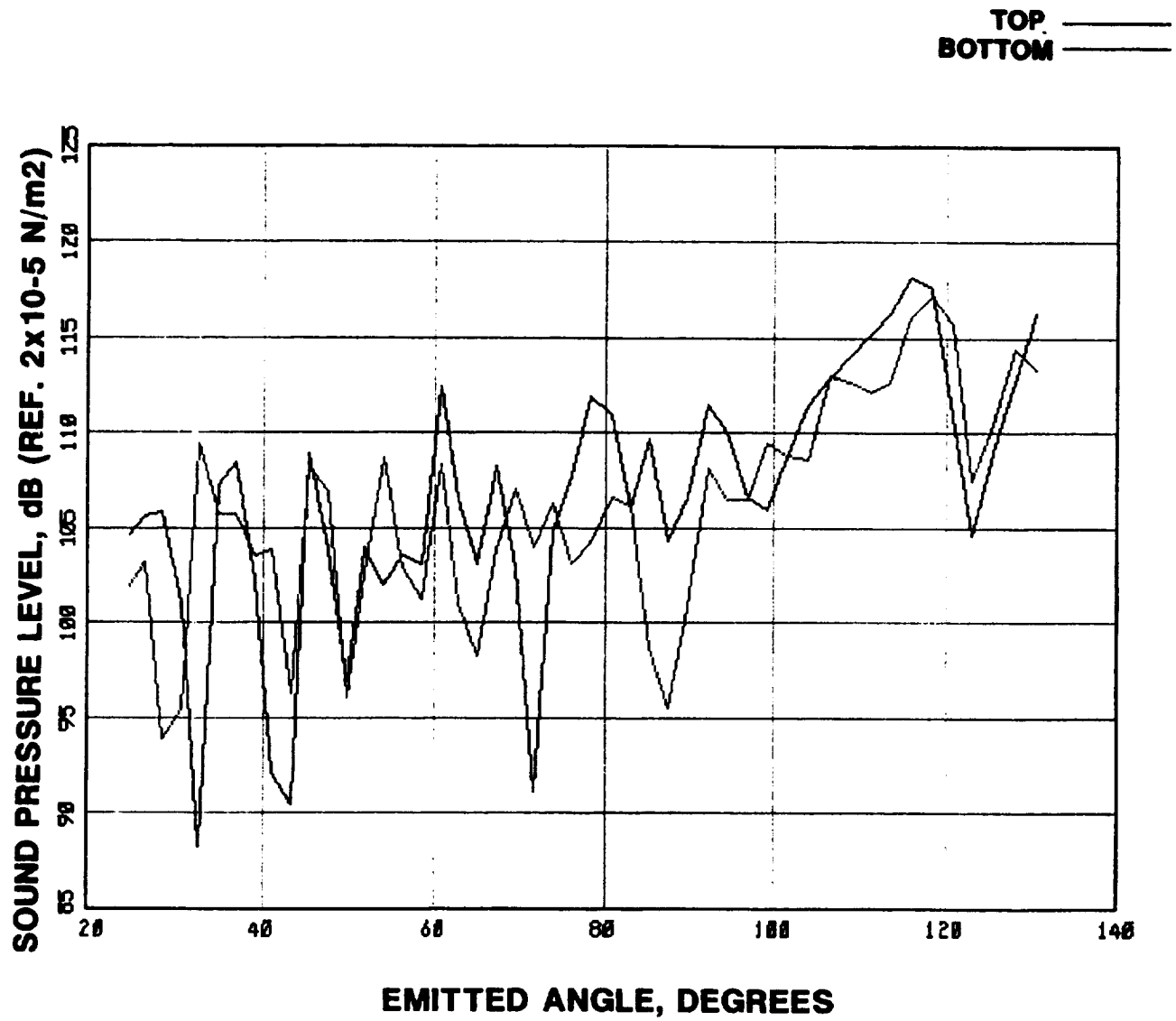
B. CENTER AND BOTTOM MICROPHONES

FIGURE 36   2 BPF DIRECTIVITY AT APPROACH

C. TOP AND BOTTOM MICROPHONES